INDUSTRIAL RESEARCH

JUNE–JULY 1960

instrumentation and control

special reference edition — two dollars

IDEAS AND APPLICATIONS

JUNE-JULY 1960 **RE**

INSTRUMENTATION AND CONTROL, *the subject of this special edition, is at once old, new, dynamic, simple, confusing, and complex. Old because the science behind it is old; new because refinements of the science are happening now; simple in concept; confusing and complex in the variety of techniques and applications.*

This issue is somewhat more technical than previous ones because it undertakes to cut through the confusion, to illuminate the subject by application-examples from the industries that use, or should use, instrumentation and control.

Three viewpoints on the significant new science of adaptive control are featured here because we believe this science will have a profound impact on many processes. Several years ago, "servomechanisms" was a word coined for an old, old science, control systems. The glamor of a vogue and the real needs of industry and the military greatly accelerated "servo" efforts. Much of value was accomplished, partly in organization of control-system knowledge and partly in development of design techniques.

However, most of the developed theory was of limited value. It was tedious to apply. Worse, it was restricted to systems with constant parameters, where variables have a linear relation. Most systems turn out to be nonlinear, so control systems were designed by trial-and-error experiment, as before the introduction of "servomechanisms."

Adaptive control offers promise for solving this problem. We now may be able to design control systems without detailed information about system parameters and without performing sometimes-impossible experiments.

Several scientists are studying "self-organizing" systems, machines which might have certain learning capabilities. (see "Automata," I·R, Spring,

(continued on page 8)

VAC **51,000** copies of this issue printed. Circulation to be audited and verified by Verified Audit Circulation Corp. (Audit report available after August, 1960.)

Industrial Research magazine is published to help management men and engineers keep informed of the profitable applications of research in all fields of industry. Its goal is to help place research on a par with other management functions, such as sales, finance, production, and engineering, and—by doing this —to help reduce the time lag between invention and production.

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the new bimonthly management magazine

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JUNE-JULY 1960

INDUSTRIAL RESEARCH

IDEAS AND APPLICATIONS FOR R&D MEN, CREATIVE ENGINEERS, AND TECHNICAL DIRECTORS

the seventh issue of I•R

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INDUSTRIAL RESEARCH: *editorial, circulation, and advertising offices, 200 S. Michigan Av., Chicago 4, Ill. Vol. 2, No. 3, June–July 1960, published bimonthly by Scientific Research Publishing Co. Inc. (Copyright © 1960). Copies of I•R on microfilm are available from University Microfilms, 313 N. First St., Ann Arbor, Mich. (See page 4 for subscription and other information.)*

ADAPTIVE-CONTROL ARTICLES

STATE-OF-THE-ART ARTICLES

DEPARTMENTS

FEEDBACK *from readers*

The technical entrepreneur

PRO . . .

Sir:
"The Technical Entrepreneur" is one of the finest articles of its kind to be put in print in a long, long time.

The thoughts expressed are so clear it seems imperative to me that the information be spread, not only throughout our organization, but among key people in research and development activities in other companies.

This one article has more than made the subscription to your excellent magazine worthwhile.

R. C. Singleton
Vice-President, Engineering
Gregory Industries

. . . AND CON

Sir:
Your article on the technical entrepreneur is interesting because it renders a decidedly Chicagoesque viewpoint; unfortunately, it is somewhat unconvincing. It seems to disregard the basic truth that you can't have your cake and eat it.

Technology, while useful if wisely applied, is not even important beyond a certain point. It is a means to an end, but should never be an end within itself. It is fine from eight to four, but had best be forgotten after that—as indeed and luckily it mostly is.

Salesmanship usually involves an element of deception and may be outright immoral. A salesman is not usually considered a gentleman, not, that is, where I come from.

A detailed discussion of some of the points in your article is superfluous, since the technological picture has been treated adequately by the best thinkers of our day.

Max F. Wulfinghoff
Professional Engineer
Erlanger, Ky.

(We always look forward to hearing from Mr. Wulfinghoff, a regular contributor to this column.)

. . . AND ON

Sir:
Certainly this article addresses itself to a problem of the utmost importance, and whether or not Dr. Hafstad's 40-year cycle (cycle of engineering shortages and quality of engineering education) materializes, the fact remains that we are faced now with developing foresighted plans for making the best use of our creative technical brainpower and, equally important, for recognizing and rewarding it adequately.

This is an important theme and I hope it will stimulate other writers to consider and publicize other variations of the subject.

Jesse E. Hobson
Vice-President
United Fruit Co.

Sir:
The April-May issue was the first issue I have read, and I must say that it is impressive not only in format, but in content. The article "The Technical Entrepreneur" is particularly interesting and a copy would be appreciated.

Robert L. Kossan
Asst. Division Director
Weapons Installation Div.
Dept. of the Navy,
Bureau of Naval Weapons

Sir:
I very much enjoyed reading the article, "The Technical Entrepreneur." It is both interesting and of value to young men entering the research field.

Hudson T. Morton
Professional Engineer
Ann Arbor, Mich.

Sir:
I just finished reading your article, and thought it was excellent. Please send me a reprint. I have submitted the questionnaire under separate cover.

Norman Alpert
Professional Engineer
Scarsdale, N. Y.

Sir:
I consider this a very fine article. Please send me a reprint.

George Cook
Mandrel Industries Inc.

Sir:
I found the article interesting, no doubt about it, but its main appeal is the information, which will prove invaluable in helping me form a philosophy of business policies.

John W. Kamola
Clarkson, College
Potsdam, N. Y.

Sir:
This is one of the best articles to appear in a publication for a long time.

Joseph Smurik
Preliminary Design Engr.
Curtiss-Wright Corp.

Sir:
The article, "The Technical Entrepreneur," is an extremely illuminating discussion of the role research and development is and will be playing in our economy. Perhaps we know about as well as anyone does the need for the entrepreneur's role in a techno-economic society.

We continue to be impressed by the content and progress of your excellent journal.

Warren S. Berg
Arthur D. Little Inc.

7

(continued from page 3)

NOTES ABOUT THE SEVENTH ISSUE

Volume 2, Number 3, Industrial Research

1959) The potentialities of these systems have been questionable; unfortunately, premature publicity and imaginative writers have injected a degree of mysticism into the subject. Yet, adaptive-control techniques are a realistic and highly promising step toward systems with some self-organizing capability.

Possibly the most important application of instrumentation and control is in large processing facilities of the chemical and oil industries. Here they make it possible to produce a uniform and predictable yield. Instrumentation systems are of extreme importance because of the large capital investment in plant and materials. The system can make the difference between profit and loss. "What Will Process Controls Look Like Tomorrow?," "Analysis Instruments—Key to Process Control," and "Instrumentation Is Changing the Oil Industry" discuss the evolution in process-control instruments, design of overall systems, needs of the present, and predictions for the future.

Instrument development has lagged aircraft performance seriously, and instrument limitations are too often an obstacle in achieving maximum performance from today's aircraft. Two aspects of aircraft instrumentation are described in this issue—re-design of the cockpit for better presentation of necessary information to the pilot, and requirements for improved safety ("Revamping the Clock-Shop Cockpit," and "Instrumenting Air Safety").

Computers have been assuming an increasingly im-

Sir:

It is an excellent article encompassing a broad subject from an open-minded viewpoint. I wonder how open-minded some of your readers are concerning your touch on politics.

H. N. Pennypacker
Albuquerque, N. M.

Heat without flame

You have done an excellent job on the article about our Thermocatalytic Combustion processes in the April-May issue, and we wish to express our congratulations and thanks.

As a result of this article, we have had many inquiries which, significantly enough, come from the top echelons of companies. It shows that your magazine certainly reaches its intended readers.

However, since "Thermocatalytic" is a registered trademark, it should have been capitalized wherever it appeared in the text to protect it as a trademark. We would appreciate a rectification.

Gerhart Weiss
Director of Research & Engineering
American Thermocatalytic Corp.

(I·R has received scores of inquiries asking for the address of the company. It is 200 East Second St., Mineola, N. Y.)

Sir:

I have been reading your magazine over the past several months with considerable interest, but with intense interest when I read the article, "Heat without Flame." Through your help, we have arranged to meet with Mr. Weiss, the author, to discuss our interest in this heater.

This is an unusual service rendered by a technical magazine and we appreciate it.

Joe Baxter Jr.
Director of Research
The Black-Clawson Co.

Artificial satellites

Sir:

I have just received a copy of your book *Stimulus*, containing my article, and I wish to thank you very much. I wish to thank you also for the fine presentation of my article in your excellent publication.

I would be most grateful if you would send me any comments you might have received on the article.

Ari Shternfeld
Moscow, USSR

(Ari Shternfeld, author of "The Use of Artificial Satellites: a Soviet Perspective," Nov-Dec '59 I·R, and the book "Soviet Space Science," invites American inquiry. His address in Russia is Liousinovskaia 55, App. 29, Moscow B-26, USSR. He understands English, but answers your letters in French or Russian.)

Penetrating rays

Sir:

I do not have anything to supplement this excellent article. But with my commercial hat on, I could wish that the writer had spent a little time with us in the Philips Co. to mention the equipments which we also are providing in some of these areas.

However, with my technical hat on I think the article covered the field adequately and that it is an excellent summarization of the ever increasing use of X-rays in industrial applications.

Dr. D. C. Miller
Technical Director
Philips Electronic Instruments

(continued on page 102)

portant role as parts of control systems. Often the question is not whether to use a computer, but what kind. Hence the article, "Analog Versus Digital Computers."

Certainly nuclear reactors are here to stay, but it has been only by means of instrumentation that we have learned enough about the workings of a reactor to design them to propel ships, produce electricity, and perhaps power aircraft. The basic problem, of "Controlling the Nuclear Reaction," is discussed by a leading reactor control engineer.

"The Rolling Mill as an Instrument" might seem to be a novel device, but using the mill as part of an instrumentation-control system is solving what was a major problem in controlling the thickness of strip steel.

These articles are meant to be definitive, but not necessarily all-encompassing, for the field is vast and the feedback limited. As usual, your feedback on this, our seventh issue, will be appreciated.

■ ■

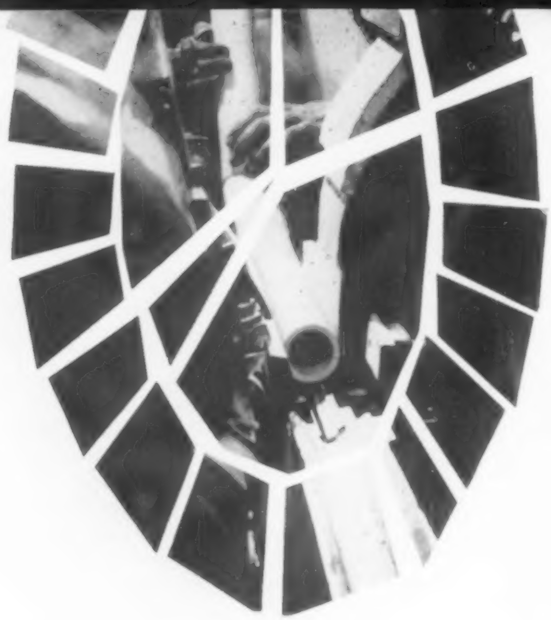
Harold Garbarino, formerly chief engineer of Magnaflux Corp. (a subsidiary of General Mills) and technical editor of Industrial Research, has been appointed technical director of I·R.

Garbarino has had extensive experience in industrial research; he was assistant director of electrical engineering research at Armour Research Foundation and, before that, development engineer at GE.

He is a graduate of the University of Colorado (BS in electrical engineering with honors) and of Illinois Institute of Technology (MS and PhD).

He is a senior member of the Institute of Radio Engineers, and a member of the American Institute of Electrical Engineers, the Society for Nondestructive Testing, Sigma Xi, Eta Kappa Nu, and Tau Beta Pi.

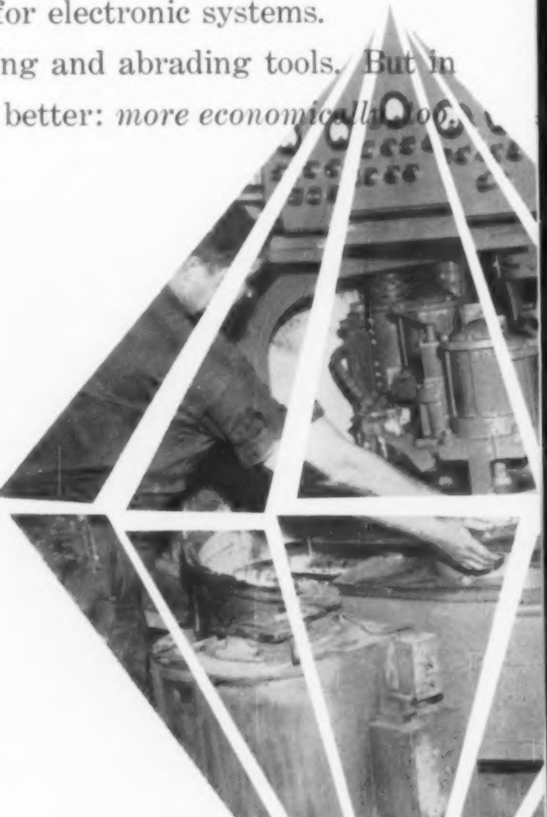
Published papers describe some of his work in various fields: magnetic circuits, electromechanical apparatus, electric-power systems, electronic circuits, reliability of components, and nondestructive testing of metal parts. He has been granted two patents. ■



DIAMONDS AT WORK

Industrial diamonds are, first and foremost, *tools*. They're used in many ways to do many jobs. Diamonds keep hardest carbide tools sharp and efficient. Diamond wheels shave jet runways to perfect smoothness. Diamond tools speed up production of precision aluminum parts for automobiles. Diamonds machine close-tolerance ceramic components for electronic systems.

These jobs *could* be done with other cutting and abrading tools. But in every case, diamonds do them better. Not only better: *more economically, too.*



ADAPTIVE CONTROL 1:

the next step in control syste

by **Dr. John A. Aseltine,** *manager of electronics plann*

"ADAPTIVE" has become an O.K. word. As defined in Potter's *Lifesmanship*, its use creates in the hearer a sense of uneasiness. He feels the term is familiar, but he can't easily put a finger on its definition.

This is not surprising. No definition of adaptive control has been accepted. So long as the term remains in this condition, it can be used to draw crowds to technical meetings or confound evaluators of proposals. However, it cannot serve to advance the promising science for which it should stand.

The word "adaptive" refers to the ability of an organism to alter itself to fit changing external conditions. The idea when applied to machines is an intriguing one; hence the widespread interest in its application. The terms "adaptive," optimizing," and (the redundant) "self-adaptive" all mean pretty much the same thing. That is, they refer to a process in which the analog of the organic adaptive principle is employed.

I would like to propose that the term "adaptive" describe systems in which mechanisms are present for:

- Measuring performance or potential response.
- Expressing the "quality" of the measured quantity.
- Modifying the system in accordance with the measured quality.

Why closed loops?

A process or plant to be controlled is shown in block diagram 1. If we know the characteristics of the plant and the nature of the disturbances, we can calculate ahead of time the input needed to produce a desired output.

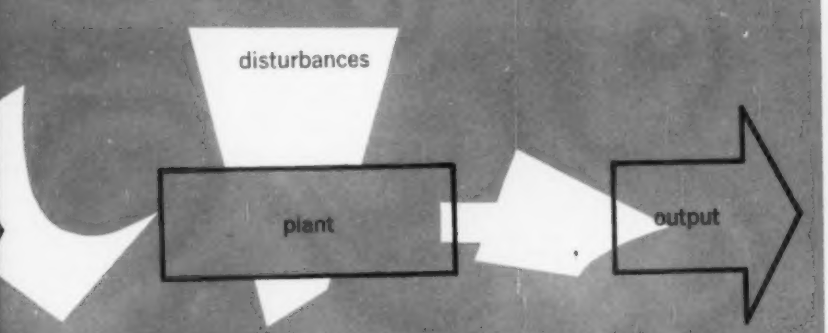
An example can be found in golf. A golfer estimates distances to the hole and characteristics of ball and club *(the plant)*; he judges wind and condition of turf *(disturbances)*; and calculates the proper stroke *(input)*.

An additional disturbance arises from the uncertainty of his own muscular reactions. Once he strikes the ball, he has no further control, and the

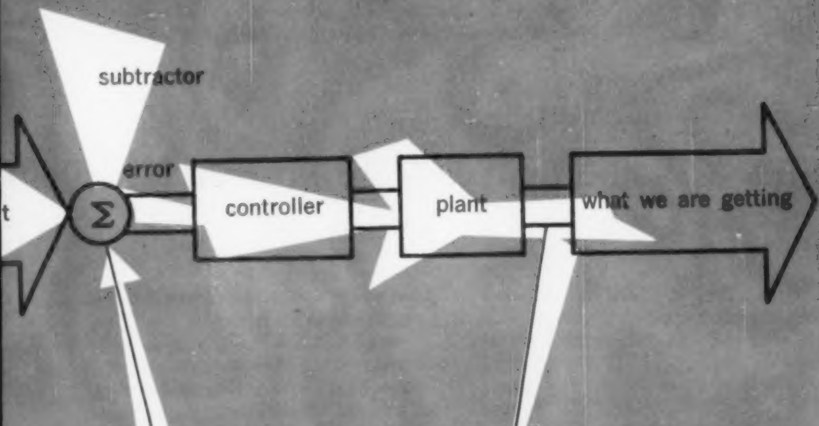
Adaptive control has become synonymous with John Aseltine through two main events. As a lecturer in engineering at UCLA (where he received his PhD in 1952), Aseltine has been teaching control systems and allied subjects for nine years. And he was in charge of a project to build an adaptive flight-control system at Aeronutronic Systems in 1957. Aseltine now is manager of the electronics planning and analysis department at Space Technology Labs in Los Angeles. He is the author of the book, "Transform Methods in Linear System Analysis."

evolution

d analysis, Space Technology Laboratories Inc.



1 **AN OPEN-LOOP CONTROL SYSTEM,** *shown in functional form, requires that input and disturbances be known ahead of time. An example is a golf game. Input is the stroke. Disturbances are wind and condition of turf.*



2 **CLOSED-LOOP CONTROL SYSTEM** *furnishes an input equal to the difference between output and what's wanted. It requires less knowledge of controller and plant, and is less sensitive to disturbances. Stability is the problem.*

system proceeds "open loop."

Of course, any attempt to add control would ruin the sport. However, sport is seldom a factor in the economical operation of an industrial process, which leads us to consider the closed loop shown in diagram **2**. The closed-loop system furnishes an input to the plant derived from the difference between what we want and what we are getting.

There are two major reasons for using closed-loop control:

- The system's operation depends less heavily on detailed knowledge of the plant characteristics—which may be uncertain, or may change with time.

- The system's operation becomes less sensitive to disturbances.

Of course the closed loop creates certain problems—for example, stability. A whole science of control has been built up in the last 30 years to study such problems. Usually these can be solved so that advantages gained outweigh added complexity. Sometimes, though, even the closed loop doesn't provide the degree of control required, and something more seems to be needed.

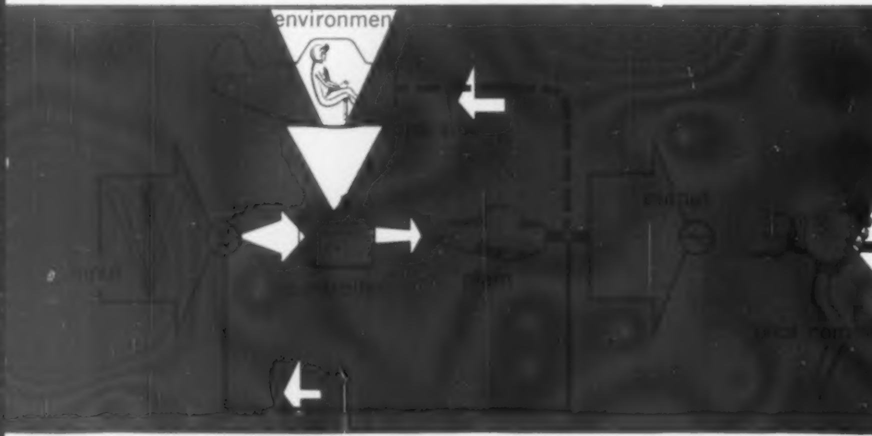
Needed: a new approach

What can be done when the environment and plant characteristics change over a range which makes conventional closed-loop control ineffective? Such a situation is encountered in the control of high-performance aircraft. An autopilot designed for low-altitude flight may be unable to control the plane near its ceiling.

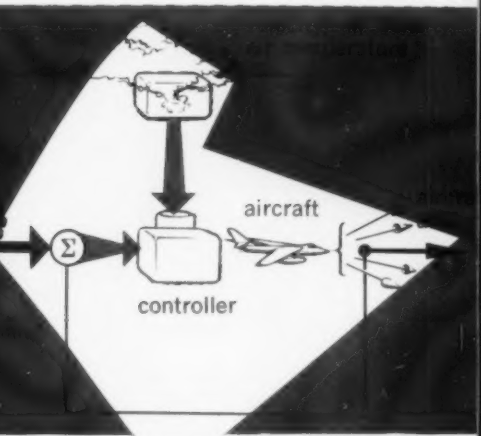
A partial answer lies in giving the pilot an ability to change characteristics of the controller as a function of measured environment and observed output. This programed control, shown in diagram **3**, is a step beyond a simple closed loop. Diagram **4** shows its application to an autopilot, where we have taken the further step of automating the changes.

When we talk of added complexity, we must be sure that results are worth added cost. In the case of the autopilot, there is no alternative and the cost must be borne, but there are cases in which a more careful examination is necessary.

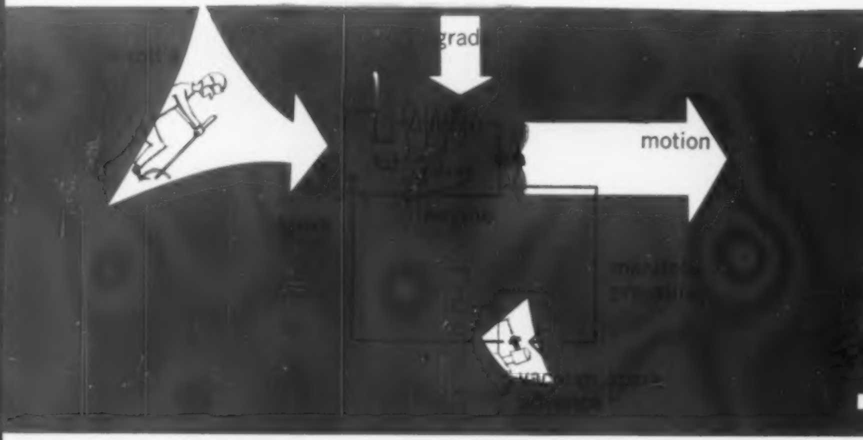
One example is the operation of an internal combustion engine, of particular interest because the first adaptive control system was demonstrated on such an engine by C. S. Draper and T. T. Li, of MIT. If we think of the problem of operating an automobile at peak efficiency, a number of control methods might be



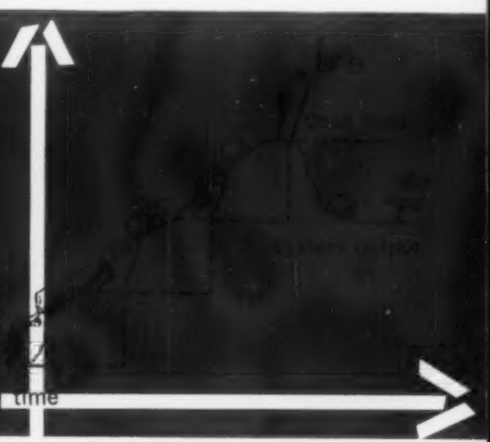
3 **PROGRAMED CONTROL** *is step beyond closed-loop system. Pilot changes the autopilot manually to compensate for changes such as altitude.*



4 **AUTOMATIC CONTROLLER COMPENSATION** *removes pilot from the control loop, but requires detailed knowledge about the environment, and costs more.*



7 **VACUUM SPARK ADVANCE** *automates the operator out of control loop, by using changes in the system. Again, detailed knowledge is required.*



8 **'EXTREMUM' ADAPTIVE CONTROL** *produces optimum plant output by comparing each new output with previous stored value, then changes controller.*

Adaptive control requires less knowledge to design the controller

considered in order of their increasing complexity.

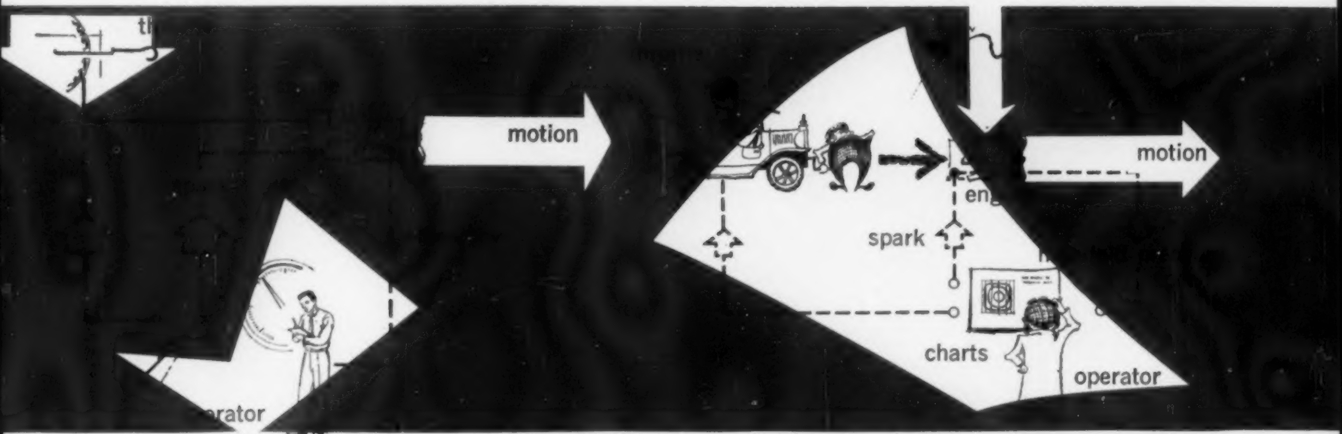
If a means of measuring efficiency directly (for example, brake-mean-effective-pressure times speed, divided by fuel consumption) were available, the operator could keep operating near maximum efficiency by trial and error. He simply would make a series of adjustments of spark and throttle until a maximum reading was obtained. His other duties, such as steering, make this impractical; large changes in grade and speed would complicate his job further.

Operator as part of the loop

Diagram **5** illustrates such a system. The operator forms a part of the closed loop. Here the system has all the features of adaptive control: the operator measures performance, determines whether operation is at peak efficiency, and adjusts the system accordingly.

Replace the operator, and an adaptive control system results. But before taking this rather drastic step, let's examine some alternatives.

Suppose now the operator has control over manifold pressure (throttle) and spark as before, and has been supplied with a manifold pressure gage and a set of charts. Now as either the grade or speed changes,



5 **MAXIMUM ENGINE EFFICIENCY** *can be maintained by trial and error. Operator must adjust spark and throttle for a maximum reading.*

6 **PRE-CALCULATED CHARTS** *can tell operator if he is at peak efficiency. Trial and error are eliminated, but data are needed beforehand.*

9 **ADAPTIVE SYSTEM USING TEST SIGNAL** *analyzes controller and plant response to the signal, then adjusts the controller for optimum performance.*

10 **'LEARNING MODEL'** *measures plant input and output, then duplicates plant. (Drawings by B. Clendenin, John Amendola Jr., Joseph Tiberio, Allan Scharf, STL)*

ut it may cost more.

the charts could be consulted and the spark adjusted for peak operation. (See diagram **6**.)

Actually, overall system operation is open-loop, since the operator depends on pre-calculated charts to tell him if he is operating at peak efficiency. On the other hand, the trial and error element is removed. If external conditions and the system to be controlled are known sufficiently well in advance to prepare the charts, this mode of operation may be satisfactory.

From diagram **6** we see that the operator himself is a part of a closed loop, as in the previous case, and we expect that if conditions are changing, efficiency of operation will depend heavily on his ability to react. In many applications, this type of operation is entirely satisfactory, but in many others removal of dependence on the operator by automation can be justified economically by increased efficiency.

The next step is incorporation of charts and the operator's control function in a mechanical or electronic device. The modern vacuum spark advance is such a device, and its use changes the system to that shown in diagram **7**. This system is analogous to the autopilot with programed adjustments in diagram **4**.

The two types of systems used as

Performance is not free; it costs money—and reliability.

examples — autopilot and engine control — are typical of two classes of control problems. The first sought a system to control dynamic response; the second strove to regulate for most efficient performance.

Both led to programed adjustment of the control system — by an air-data computer for the autopilot, and by a vacuum spark advance for the engine. In each case the added complexity had to be justified by increased performance.

Now adaptive control represents a further increase in complexity (and in performance). These gains are not free; they cost money and possibly reliability, and their addition to a system must be examined carefully and well justified.

The steps leading to consideration of adaptive control are:

- If we know the characteristics of the plant and are not concerned with effects of external disturbances, no closed loop is needed. We simply can calculate the input needed to provide desired response. A controller and closed loop relax requirements for knowledge of plant and disturbances.
- If the plant characteristics are changing, it may be well to give an operator means for changing the controller. If such changes can be made by a human operator, they may be based either upon his observation of performance or on his use of pre-calculated curves.
- It may be desirable to automate the system completely by building pre-calculated curves into a programer, which changes the controller in accordance with measured environmental changes.
- If uncertainties still remain that preclude fore-knowledge of system characteristics needed for the programer, we may wish to automate the operator's method of control by observed performance. *This is adaptive control.*

Draper and Li's 'extremum' control

As mentioned earlier, Draper and Li were first to demonstrate adaptive control. Their work in 1951 at MIT was concerned with control of an internal combustion engine using what they termed the "optimalizing principle." The only distinction I suggest between the words "optimalizing" and "adaptive" would be to say that the former is applied more often to regulators where most efficient performance is desired.

Since Draper and Li's control system was designed to seek a maximum or a minimum, the term "extremum" adapation might be applied. (Incidentally, this term apparently was used first in Soviet literature.)

Although Draper and Li have described several methods, they demonstrated experimentally what they call a "peak-holding system." Its operation is based on a peak-holding device which stores a value of plant output for comparison with a subsequent value.

The controller is adjusted by steps producing an output which might look like the solid line in diagram **8**. Before each step, plant output is compared with the last value stored by the peak-holding device. The difference becomes zero as the plant output passes its peak. This is the signal for the controller to begin stepping in the opposite direction. Once the peak has been found, the stepping continues back and forth across the peak.

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In Draper and Li's experiment with an internal combustion engine, the stepping was applied alternately to spark and throttle. Plant output used was brake-mean-effective-pressure as a measure of efficiency.

Experimental results indicated that the principle was sound, and a commercially available controller based on the Draper-Li principle has been marketed subsequently (trade named "Quarie").

High-speed response

While a direct measurement of performance is often possible in systems like the one just described, the problem of maintaining a desired transient response is more difficult. Reason: the problem of measuring performance. Again, an adaptive system must have a measurement of performance, a translation of this into a measure of quality, and a means for using it to modify the system.

If transient behavior measures performance (as it does, for example, in an autopilot) then it somehow must be measured.

It is important that the measurement be of *potential* performance. That is, we must know how the system *would* react *if* it were to be subjected to an input command or a disturbance. It is not enough to know that the error in the closed loop is zero — any stable system at rest has this characteristic.

The problem is complicated further by our desire not to disturb the system unduly by whatever testing must be done. Two basic methods of transient performance measurement have been used in adaptive control. One is simply to apply a test signal, preferably a small one, to the system, and then measure response. The other infers the same information from measurements of plant output and input under normal operation.

Test signals

A system studied by the author, using test signals, is shown in diagram **9**. The test signal happened to be low-level white noise, which provided certain advantages in measurement. The output of the response computer was equivalent to system response for an impulse test function.

This response computer output tells whether the system tends to oscillate or is too sluggish, the optimum being somewhere between these two conditions. The function of the block marked "figure of merit" is to analyze the response computer output and adjust the controller accordingly.

A simulation of the system described above was set up on an analog computer. Simulated flights of high-performance aircraft with this adaptive feature in the autopilot showed that dependence on pre-calculated programs was unnecessary.

The objective was an autopilot that could be used without the long delays ordinarily involved in gathering test data to design a programer. Although an adaptive autopilot would be more complex than a programed one, the earlier operational availability of the aircraft would justify its use.

The 'learning model'

As an example of the alternate approach to performance measurement —the use of plant input and output to infer it—consider a system studied by M. Margolis and C. T. Leondes, at UCLA. They propose using a "learning model," a device that changes its characteristics to simulate the plant.

Without going into details of operation, we still can see that if the learning model changes itself to duplicate the plant through measurements of the plant's input and output, it represents a measurement of plant characteristics. In turn, this can be used to change the controller appropriately. Block diagram **10** illustrates the system. The knowledge of plant characteristics is entered in the computer, which generates adjustments for the controller.

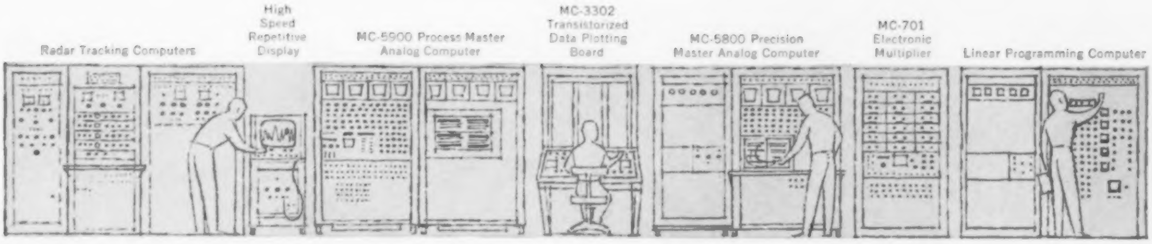
It would be unfair, in describing this system and the autopilot preceding it, not to point out that the general problem of adaptive control is far from solved. These adaptive systems have been demonstrated only in very simple plants, and much work remains to be done before they can be considered ready for application to every industrial control problem.

Two main points

Two main points emerge from all this. First, not many of the systems now called "adaptive" actually are. At least, they are not adaptive in the sense that they have performance measurement, translation of measurement to a signal related to quality, and closed-loop adjustments of the controller. *(Despite whether you accept this definition, you should determine from proponents of adaptive control what theirs is!)*

Second, adaptive control, like most other refinements, doesn't come free. Its cost should be compared carefully with possible gains before plunging.

As for the future, adaptive control is here to stay. It is a technique crying for application. ∎



Some people can prove man and mouse are identical

It's all according to the points of similarity you choose. *Differences* are what really *prove* the superiority of man over mouse. Computers have differences, too. In fact, it's in these differences that the CSI-designed MC-5800 obsoletes every other Analog Computer. The best proof lies in

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Specifications

- Exclusive dynamic memory makes automatic iterative solution of statistical or optimization problems a reality.
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- Lowest amplifier grid-current $<10^{-9}$ ampere.
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- Will program 134 amplifiers, 30 electronic multipliers, 18 diode function generators, 2 time-delay generators, 8 relay amplifiers, and 6 servos from one 2128-hole patchboard.
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- Passive networks stabilized at $< 1°C$ above room ambient — no oven required.
- EVERY SPECIFICATION IS GUARANTEED TO BE TRUE PERFORMANCE STANDARD — IN SUSTAINED OPERATION.
- Only diode function generators utilizing resistors, potentiometers, and diodes of equal quality to those in computing networks.
- Only diode function generators with individual hi-lo gain positions for *each* segment.
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ADAPTIVE CONTROL 2:

a comparison of adaptive and conventional

ALTHOUGH THE APPLICATION of adaptive techniques to feedback control systems is relatively new, highly developed adaptive systems are very old, since they occur in nature. For example, the human eye adapts by adjusting its pupil diameter as a function of average light intensity received from an object under observation. The eye adapts well enough to maintain the image transmitted to the retina at a uniform average intensity level, even though the object being viewed may be very bright or very dim.

Many other physical processes in the body entail some form of adaption, and they often are based on principles far more complicated than those involved in light adaption. The basic principle of light adaption of the eye is used in one of the flight-control systems to be discussed.

The feedback control system

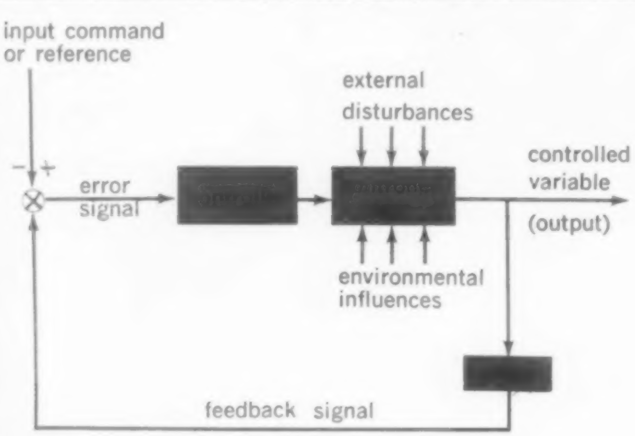
Before describing an adaptive control system, an ordinary feedback control system without this feature should be understood. (See diagram 1.)

An input command, frequently an electrical signal, determines the power supplied by the controller to actuate the controlled system. (In an airplane, an electrical signal controls the force on a hydraulic piston that moves a rudder.)

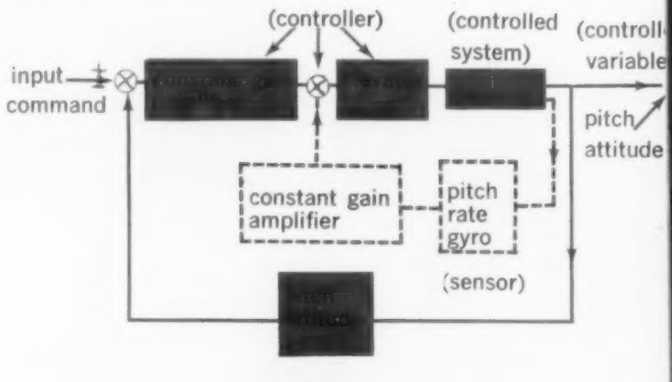
The controlled system reacts, and the output or reaction is measured by a sensor. The sensor reconverts the output to a signal of the same type as the input, with which it is compared.

The feedback control system takes the difference between the input command (frequently a reference) and the output of the sensor, this difference being the error signal. If the output is precisely correct, the signal from the sensor will cancel the input command exactly; there will be no error signal, and no further change in output will occur.

If, instead, the output is too large or too small, the sensor will produce a signal larger or smaller than the input. The difference will be an error signal that corrects the output until the error signal is reduced to zero. If an external influence—such as atmospheric turbulence—affects the controlled sys-



1 **TYPICAL FEEDBACK SYSTEM** *compares input and feedback signals to actuate the controller. Signals might be electrical or mechanical values.*



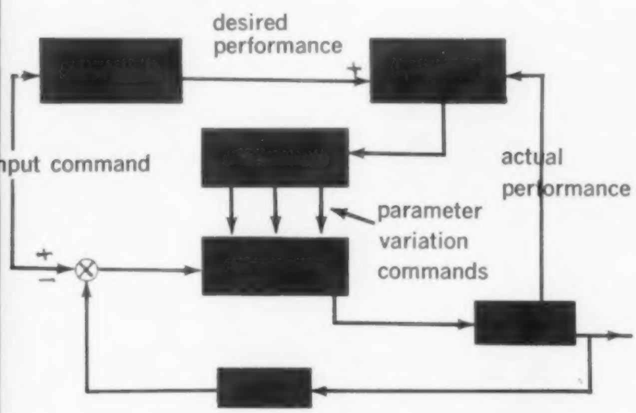
2 **AUTOPILOT PITCH-ATTITUDE CONTROL** *exemplifies system with second feedback loop. Rate of output change affects controller.*

control systems

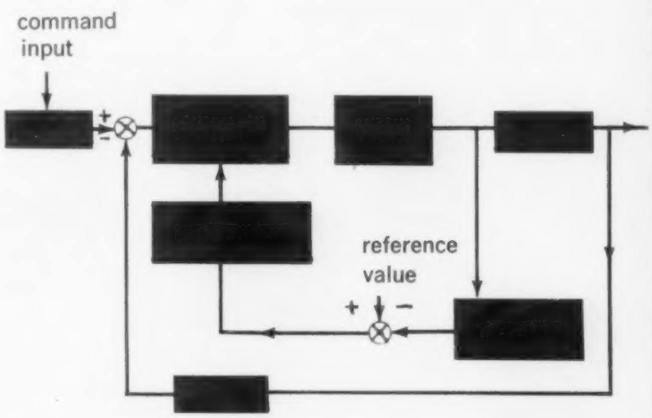
by **Luther T. Prince,** *supervisor, Minneapolis-Honeywell, and* **Dr. Finn J. Larsen,** *vice-president*

Luther Prince, an engineering supervisor in the advanced flight system section at Honeywell's aeronautical division, currently is responsible for the development, design, and flight-test evaluation of adaptive flight-control systems. He also is charged with application of advanced synthesis techniques to the solution of complex aircraft and missile-control problems. Prince received BS and MS degrees in electrical engineering from MIT.

Co-author, Finn J. Larsen, a native of Norway, joined Minneapolis-Honeywell Regulator Co. in 1948 as a research physicist, and worked his way through titles of research supervisor, director of ordnance engineering, and director of research to vice-president of research, the position he has held since 1959. Larsen received his PhD in physics at Iowa State College. In 1953, he was selected as one of Minneapolis' "Leaders of Tomorrow" by Time magazine and the Minneapolis Chamber of Commerce.



3 **COMMAND INPUT** *adaptive system compares actual and desired performance, analyzes the difference to change the controller.*



4 **ADAPTIVE SYSTEM** *with model compares system and model outputs to actuate controller. Model output is equal to desired system response.*

The adaptive control system is the next logical developme

System performance is measured, compared with

tem, the output will change and the controller will correct the system.

Such an ordinary feedback control system is designed to function properly with fixed parameters. For example, the hydraulic piston always reacts in the same manner for a specific error signal. This type of operation is completely satisfactory if the characteristics of the system being controlled do not change significantly during operation.

Shortcomings of ordinary systems

In many instances, however, environmental changes affect the controlled system characteristics such that original values of the control parameters no longer provide satisfactory performance. When this happens it becomes necessary to change control parameters, and thus minimize any changes in over-all performance of the control system.

For the control system previously described, this means that the hydraulic piston (or rudder) should be forced to react differently for the same error signal whenever the characteristics of the airplane change significantly.

Essentially, this is the same thing a good pilot does when flying a high-performance airplane. Flight characteristics of an airplane are influenced greatly by airspeed and altitude. At high speeds and low altitudes, ordinary control stick motion could cause maneuvers violent enough to tear off the wings.

Control changes in stick sensitivity of 30 to one are not uncommon in high-speed aircraft. In order for a pilot to fly an airplane safely during great changes in environment, he must "adapt," that is, alter the manner in which he controls the airplane as its flight characteristics change.

The designer of automatic flight control systems for high-performance aircraft and missiles is faced with the same problem. He must design the flight control system so that certain parameters can be changed automatically while the system is operating.

The controller unit must be capable of compensating for flight changes so that performance of the overall system remains unchanged. (Diagram **2** gives a simple example of one technique for such compensation.)

'Tailoring' control

In a conventional control system, compensation for changes in flight characteristics can be accomplished (though at great expense) by "tailoring" the control system to the airplane. In other words, the system is designed so that certain control parameters can be adjusted automatically in flight.

These adjustments are determined during preliminary system design, and the values established by using the best available prediction of how a particular airplane will perform in flight, subject to its environment. During actual operation, data such as airspeed and altitude are used to identify the flight environment so control parameters can be established at their predetermined values.

This method of designing flight-control systems is becoming unsatisfactory because proper design of the control system is greatly dependent on an accurate knowledge of the airplane's flight characteristics. In most cases the data are *not* known very accurately. Consequently, extensive flight testing must be done before a satisfactory system is developed.

As airplanes and missiles fly higher and faster, the problem becomes more acute because predicted performance characteristics are known less accurately, the flight environment changes more drastically, the cost of extensive flight testing becomes prohibitive, and, most important, the vehicle is far more difficult to control.

Current trends in missile and aircraft design indicate that controlling future vehicles will require more advanced concepts to minimize problems in designing flight-control systems. Adaptive control offers much promise for reversing the trend towards more costly development of flight-control systems.

How does adaptive control differ?

The basic difference between adaptive and conventional flight-control systems lies in how the control system is adjusted to optimize performance. Intelligence used to adjust the adaptive flight-control system is based on what the airplane experiences during actual flight, and the control system characteristics are changed continuously!

automatic process control.

ndard, and then adjusted.

The latter is extremely significant since it means not only that an adaptive system will provide superior performance in an airplane when flight characteristics change, but also that the same control system can perform satisfactorily in a wide variety of aircraft and missiles. Since design and development constitutes the major cost of many modern flight-control systems, economic advantages are great.

Several characteristics common to all adaptive control systems are:

- A built-in standard of desired performance.
- A means for presenting this standard in a form readily interpreted by the control system.
- A means for comparing actual with desired performance.
- A method for using results of the comparison to alter the control system as the need arises.

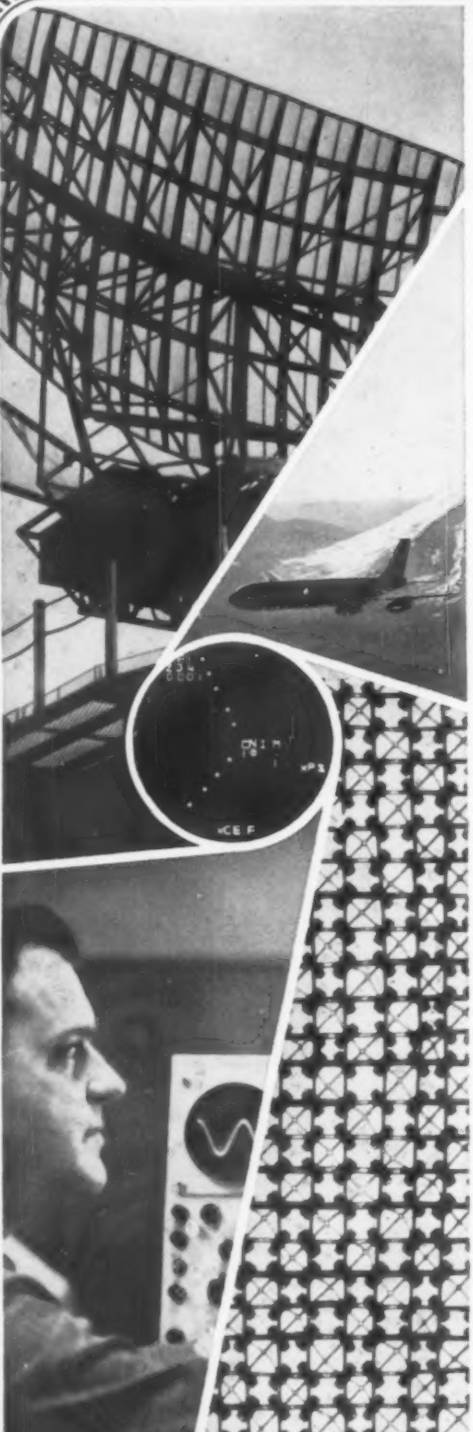
Three techniques

Three broad functional categories encompass most of the feasible approaches to adaptive flight control: adaption by evaluation and modification of system responses to *command* inputs; adaption by evaluation and modification of system reponse to *test* input signals; and adaption by evaluation and control of specific system *interrelationships*.

The command-input type of adaptive control can be understood readily by referring to diagram **3**. Note that the lower portion of the flight-control system is the same as in diagram **1** except that the controller is adjustable.

If an input command—such as the signal which would result in an upward motion of the airplane's elevator (and the beginning of a climb) is applied — the performance model would electrically simulate the aircraft response in the correct manner for speed and altitude. At the same time, the aircraft would respond and a sensor (not shown) would measure the response and send an electrical signal to the signal comparator.

The two signals corresponding to desired and actual performance would be compared. If they were alike, no change would be made in the adjustable controller. None should be made since actual performance is precisely like desired performance.



If actual performance were different from that desired, the signal comparator would detect the difference and send a command to the performance analyzer to change the response of the aircraft. The performance analyzer would determine the amount of adjustment to make, and then change the response by adjusting the controller.

The second functional category listed is adaption using a test input signal. This type of control is little different from the command input. As the name implies, a small test signal is put into the system periodically, and the flight-control system is matched regularly to a model.

Advantage of this type over the command input is that adjustments of the control system are made frequently, and the system always should be operating near its optimum performance level.

The third type of adaptive control system is shown in diagram **4**. In this variation, any input signal goes directly to the model, and its electrical output is controlled to desired performance. The aircraft follows performance dictated by the model if the adjustable controller is kept at the highest possible setting. If the setting is too high, the aircraft will oscillate.

The purpose of the limit-cycle detector is to sense minute oscillations and to keep the adjustable controller set to a level at which oscillations remain insignificantly small. When the system operates at a point of minute oscillation, response of the flight-control system is the best possible. The system then will follow the desired command signal from the model accurately.

A particular advantage of this adaptive system is that it requires neither a command input nor a test signal to remain adjusted properly. As flight altitude increases, for instance, the response of the system is increased automatically to provide larger elevator motion for a certain stick motion. Discrepancies between model output and response of the airplane are minimized at all times.

Flight testing in progress

A completely adaptive flight control using this principle has been designed and flight tested by Minneapolis-Honeywell. More than 50 successful flight demonstrations have been made in the supersonic *X-15* aircraft, and plans for further flight testing are underway.

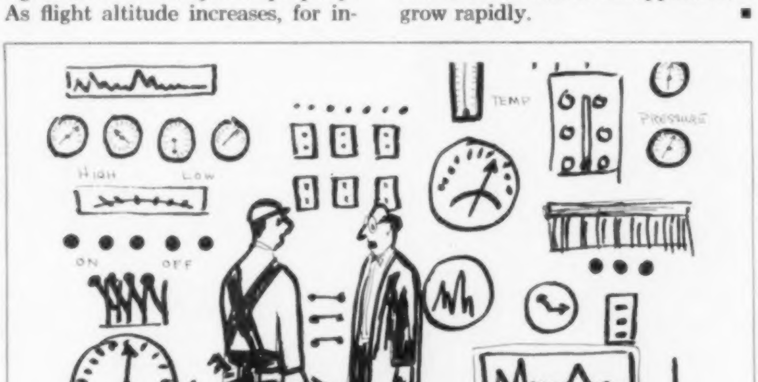
The adaptability of the system will be demonstrated thoroughly since the *X-15* will be operating both at extreme speeds in air and at the beginning of space where aerodynamic controls are ineffective. At space altitudes the aircraft will use reaction jets for maneuvering. It is expected that this type of adaptive system will prove feasible for control of craft operating both in and out of the earth's atmosphere.

Other applications

While the illustrations given are for flight-control systems, adaptive-control techniques can be applied to any feedback-control system. It is profitable to use adaptive control whenever operating conditions cause variations in the functioning of ordinary controls.

A factory machine operating under both heavy and light loads might function much more effectively with adaptive control. Or a single adaptive machine control might be operable with a variety of sizes and types of machines.

While adaptive control is currently in an early stage of development, its flexibility and ability to perform otherwise impossible control tasks will make its applications grow rapidly. ∎



"I can't find anything wrong with it physically, it must be psychosomatic."

alternative techniques for ad

CONVENTIONAL AUTOMATIC CONTROL systems have been built around the concept that dynamic characteristics of the process and performance desired of it are well known. Based on linear analysis and synthesis, automatic controls such as voltage regulators, speed controls, and servomechanisms have performed satisfactorily over the years providing certain features were incorporated.

Automatic control of new energy sources, or of the manufacture of chemicals and petroleum products, or of missile guidance are typical of new processes where dynamic characteristics are not well known and new control techniques are required.

Adaptive control is foremost in the list of new techniques for controlling such systems. By means of adaptive control, characteristics of the controller or its input signals are changed to adapt to changes in process characteristics, performance requirements, or the nature of reference input.

A major advantage of the adaptive idea is that it frees the designer from linear-control concepts and emphasizes possibilities attainable with non-linear controls.

Linear-control systems

In a linear-control system the following premises are generally true:

- *Command characteristics are known* and are capable of being handled by a linear controller.
- *System performance criteria are known* for an actuating signal within certain specific values.
- *The controlled system characteristics are constant,* or variations with time are sufficiently small to be neglected.
- *Output and input are synchronized,* or have a distinct relation to each other. This often means that a manual operation is required to set initial operating conditions of the system.

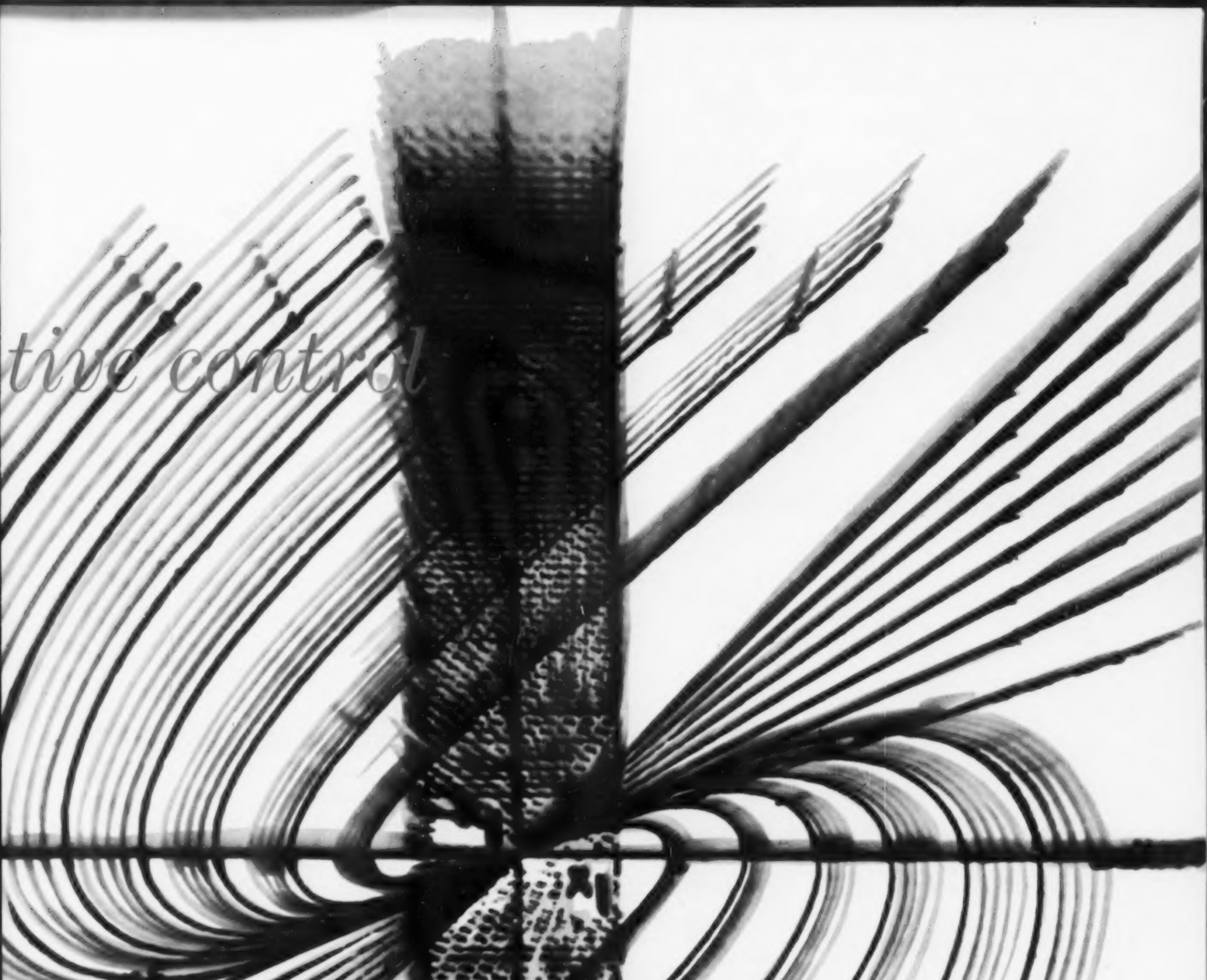
It follows that response time of the linear system is independent of command magnitude, but response magnitude is proportional to command magnitude. In addition, changes in gain or time constants of the controlled process transfer function can alter the form and time response of the error materially.

by **Harold Chestnut,**
control systems engineer,
General Electric Co.

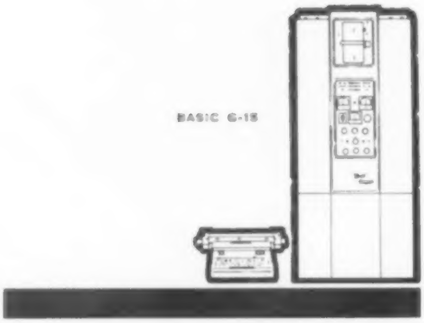
Co-author of the books, "Servomechanisms and Regulating Systems Design," Vol. 1 and 2, Harold Chestnut was honored by election as the first president of the International Federation of Automatic Control. After receiving BS and MS degrees in electrical engineering (MIT '39, '40), Chestnut came to GE and supervised part of the advanced engineering program. Later he worked in systems development, advanced development, guided missiles, and marine systems sections. He joined the general engineering laboratory in 1956 as control systems engineer.

Adaptive cont

tive control



es designers from linear control limitations and enhances possibilities of non-linear systems.



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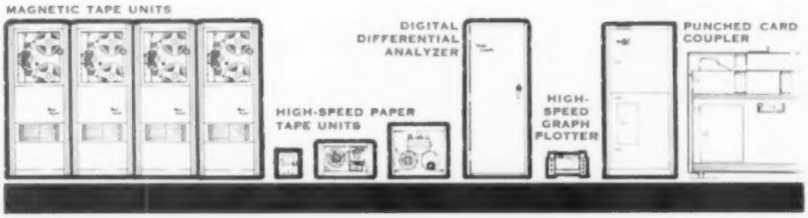

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Non-linear control systems

Although the term "adaptive control" is of relatively recent usage, practical systems not limited by these assumptions of linearity have been available for many years. Because of incomplete instrumentation of the process, or because of an inability to measure many of the significant process parameters, it has been necessary to control processes for which incomplete knowledge of the process existed.

Further, the system characteristics for many processes are inherently non-linear or time-varying, and wide variations occur during normal operation. For example, in some nuclear reactors where the reaction rate is a function of the power level, the reactor output may vary over a range of a million to one.

Or, the velocity of an airplane may range from less than 100 mph at landing to more than 1,000 mph in flight. Or, in a chemical process, heat-transfer functions or reaction-rate equations may change as much as 100 or 1,000 to one. Such changes completely invalidate assumptions of constant-process characteristics.

As adaptive control ideas become more widespread, designers are considering systems for which the commands, required performance, and plant characteristics are unknown.

They can do this because an adaptive control changes the control parameters or the control response to improve overall control system performance. The objective of an adaptive-control system is to have the controller self-adjust, or self-optimize, performance of the system according to changing system conditions. The control demonstrates some logic or decision-making ability to sense one or more characteristics important to the control, and then takes appropriate action.

Through adaptive-control techniques, nonlinear-control schemes have been developed in which response time is somewhat proportional to the magnitude of command, but the magnitude of error response is relatively unaffected by the command magnitude.

Types of adaptive controls fall into four main categories:

- Input (reference) signal sensing.
- Performance (or actuating signal) sensing.
- Controlled-system sensing.
- "Extremum" adaptive, or controlled-variable, sensing.

Input sensing

Input-signal-sensing adaptive controls sense the input (or reference) and change controller characteristics to accommodate input changes.

An application of input sensing from the early days of radio is automatic-gain control. Because of fading or other variations in the radio-frequency, input-signal level, output to the audio stages would fluctuate correspondingly if the amplifier had constant gain. The amplifier-gain changer senses the deviation of average output magnitude from the gain-changer reference and adjusts the amplifier gain to hold a constant average output.

A method of input adaptation used extensively is the changing of gain or time constants with an outside environment. For example, characteristics of high-speed, high-altitude military aircraft vary broadly with changing speed, air density, and other parameters, Use of air-data computer information to alter the autopilot controller by changing gain and time constants adapts the controller to changing environmental conditions.

Performance sensing

Performance adaptive controls sense the performance and use it as a criterion for establishing controller characteristics. Gain and time constants themselves are controlled in response to measurements of the error characteristics.

One way of automatically changing gain characteristics of the controller is to use non-linear elements in the controller itself. For example, a system might have a low controller gain with a low error signal and a high controller gain with a high error signal. Systems such as these have a fast response to a large error, but a slow response to a small error.

For some control systems, the error after a given time interval is of great significance. An example is an aircraft preparing to land. Velocity and position at touchdown are the quantities of interest, and these quantities are established by the control of the plane during the last half mile before touchdown.

The error signal predicted for some future time can be used to actuate the controller. By this technique, faster system response also can be obtained.

Controlled-system sensing

Emphasis has been focused on the control of systems in which the controlled process varies so greatly that maintaining constant controller pa-

(continued on page 36)

...NEWS IS HAPPENING AT NORTHROP

Solving the Problems of Space Electronics at Nortronics' New Department of Advanced Research

by Dr. K. N. Satyendra

Director of Research, Nortronics Division
Northrop Corporation

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(continued from page 32)

rameters, or allowing for controller parameter changes in a pre-programed fashion, has proven inadequate. Examples are controls for chemical processes over a broad range of physical and chemical characteristics, or controls involving time-varying parameter systems. Missile flight characteristics from outer space to reentry and landing are also representative of broad system variation.

Measurements of actual controlled system characteristics are used in these controls to provide information by which the controlled characteristics are modified. One method for evaluating controlled system response is to introduce a small periodic signal, such as an impulse or sinusoidal disturbance, into the controlled system. The effects of the signal on the system are analyzed and controller characteristics altered automatically.

A particular application of this principle can be made without introducing a separate signal by using components present in any input that happens to be present. Depending on the frequency alone, the controller gain can be adjusted over a wide range to keep the response essentially constant.

A different approach to control-system operation is the use of logic switching and a control signal source of fixed magnitude and adjustable time duration and polarity. The basis for the logic is the magnitude of error, error-rate, and other controlled-system responses to the signal source. This type of control is suggestive of the operation of digital-computer logic and methods for arriving at solutions.

Extremum' adaptive systems

In "extremum" adaptive systems (see article, *Adaptive Control 1*), the control is to be adjusted to yield the optimum (usually maximum or minimum) output. There are generally one or more inputs and several outputs, one of which is the most significant. The most significant output might be system efficiency, operating time, or unit-product cost.

In extremum problems the optimum output value is practically constant for small changes in the input. Another feature of the optimum condition is that a large change in input, either an increase or a decrease, causes the output to change from the optimum. It is necessary to determine the output, either by measurement or by computation, and use the output and/or rate of change of output in some fashion to control the system.

Logic optimizing control

Considerable attention recently has been given to optimizing controllers similar to one called "Opcon" developed by Westinghouse. These controllers use the extremum-adaptive concept. The controller supplies an input to the controlled system based on a logic program derived from output response to inputs chosen by the logic equipment. An input is supplied the controlled system and output is measured some time after transients subside.

If the output is better than previous input values tried, an additional step of input in the same direction is attempted. This usually is done with one or two inputs so the logic circuits are kept rather simple. For more complex controls, in which many variables must be adjusted to obtain an optimum, it may be necessary to employ output signal rate changes as control criteria, requiring a more comprehensive computer.

In each of the extremum control approaches employed so far, principal emphasis has been placed on a static or slowly changing solution to the optimizing problem. For more rapid solutions, more extensive computations are necessary.

Preceding examples show various ways in which adaptive-control ideas are being employed to obtain more flexible control performance. The rapid development of improved information processing equipment and tools to sense, convert, remember, compute, regulate, and perform other intelligence functions are providing control-systems engineers with the means for incorporating more sophisticated judgment and "thinking" into their controls.

These controls, with their ability to adapt to changing processes for which the characteristics or requirements are incompletely known or changing in an unpredictable fashion, are making possible new applications of automatic control in military, industrial, and utility fields. ■

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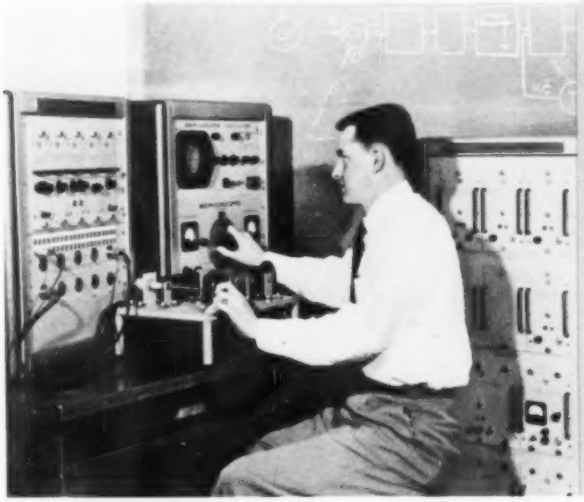

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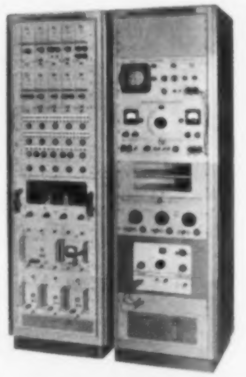

RACK-MOUNTED CABINET UNIT

Five models provide high-accuracy measurement of phase, transient response, and gain; wide range coverage: .001 to 100 cps; fast direct setting and readout; and precise, rapid results. They cover all ranges and generate sine waves, modulated carrier waves, and square wave (Model H does not generate square wave) phaseable signals with respect to either electronic linear sweep or sinusoidally modulated reference signal.

Here are some of the vital areas where SERVOSCOPE solves problems fast: aerophysics ▪ flight test instruments ▪ in-flight instruments ▪ airborne radar seeker servo systems ▪ network response ▪ computers and servomechanisms ▪ autopilot and damper testing simulating rate gyro ▪ frequency response characteristics of components and system loops of autopilot and aircraft flight controls ▪ antenna servo drive tests ▪ aircraft electronic servo system testing ▪ servo system analyses in servo test program (flight training) ▪ frequency response on electro-hydraulic servo system ▪ testing of radar systems.

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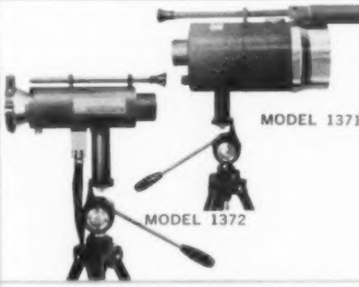
Autopilot Analyzer



MODEL 1371

MODEL 1372

4. ▪ SERVOFRAX® Arsenic Trisulphide Glass for Infrared Equipment

These stable, non-toxic, non-corrosive lenses have many applications in industrial systems utilizing infrared radiation. They transmit infrared wavelengths from 1 micron all the way up to 12.5 microns. Exceptional optical properties make them outstanding refractives. Standard and special optical shapes are available, including windows, simple or compound lenses, prisms, and domes. Single elements may be as large as 18" in diameter, while multi-element units are unlimited in size.

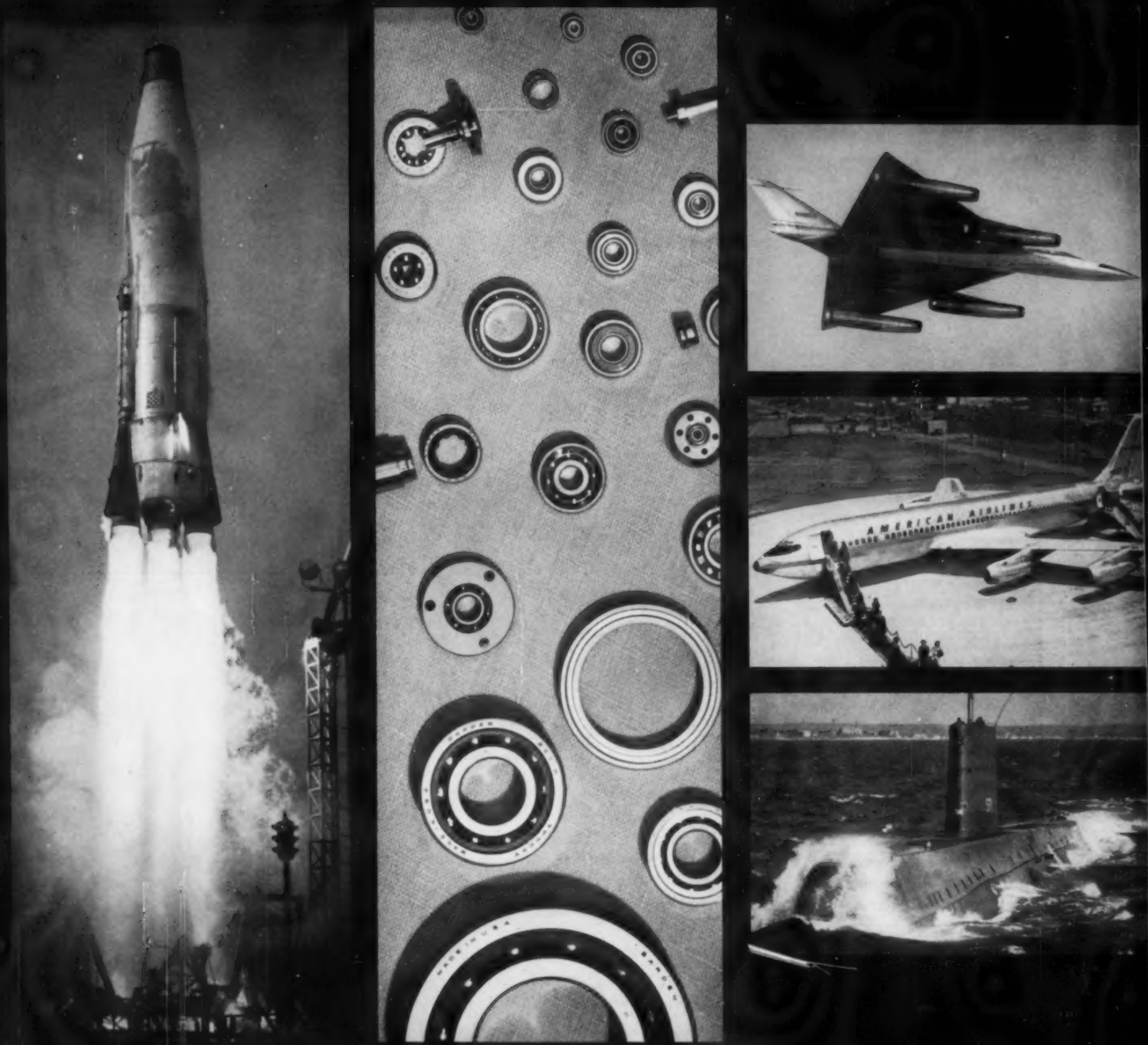
5. ▪ SERVOTHERM® Thermistor Bolometers

These thermistor infrared detectors give fast, accurate, remote detection of radiation from ambient to 1000°C. Uniformly sensitive throughout entire visible, near infrared, and far infrared spectrum. Sealed housings, rugged construction afford use under wide range of operating conditions. Speed of response: .001 to .012 seconds, depending on model. SERVOFRAX windows for wavelengths from 2 to 12 microns. Other window materials and time constants available on special order.

6. ▪ SERVOTHERM® Infrared Radiation Pyrometers (1371, 1372)

These pyrometers sense heat by utilizing the infrared spectrum. The Model 1371 Laboratory Pyrometer, with the fastest infrared mirror-optical system on the market, gives full coverage of the infrared spectrum. Range covers 2800°F to 120° F (down to less than 50° F with Model 1353 Cooler). The Model 1372 Industrial Pyrometer, designed specifically for industrial process control, covers the heat spectrum from 1 to 12 microns. Range comparable to the Model 1371. Extremely fast response; control accuracy of ± 1%.

SERVO CORPORATION OF AMERICA 111 New South Road, Hicksville, L. I., New York



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THE BARDEN CORPORATION, 232 Park Avenue, Danbury, Connecticut
Western Office: 3850 Wilshire Boulevard, Los Angeles 5, California

RESEARCH
trendletter

June-July, 1960

Dear Sir:

Instruments for measurement and process control are a big business. Sales of such instruments are expected to reach $4½-billion this year, or 15% more than last year, according to Dept. of Commerce projections.

Most of the predicted increase will occur in process-control equipment because of significant increases in expenditures by chemical and petroleum-refining industries (18%) and ferrous and non-ferrous metals industries (56%)

A larger proportion of these outlays are being devoted to modernization in 1960 than in previous years, which means that a considerable proportion of capital investment goes for instruments. Spending for laboratory facilities in 1960 by government and private industry is expected to be about the same as in 1959.

About half of the scientific and process-control instruments available today were not in existence before WW II. Included are instruments for R&D, surveying, astronomy, measuring, recording, controlling, and testing, and component instruments for use as parts of more complex systems.

An improved scanning photometer to determine wavelengths of spectral lines on a spectrographic plate has been developed by the National Bureau of Standards, Wash. 25, D.C. The instrument optically scans a 0.5-millimeter wide (.02 in.) portion of the plate and then presents, on a cathode-ray tube, a curve of spectral line density versus wavelength. The instrument was developed to help automate the processing of a large volume of spectrographic plates.

NBS also has made available a set of 24 standard samples of materials suitable for spectrographic and chemical analysis of petroleum products. For example, metal impurities in engine crankcase oil can give an indication of engine wear.

Differential pressures as low as .0001 millimeters of mercury can be read with a wide-range electronic micromanometer introduced by Trans-Sonics Inc., Lexington 73, Mass. The instrument has eight full-scale ranges from .01 mm of mercury to 30 mm of mercury. Response time is about 10 milliseconds.

High accuracy in measurement of loads is claimed using a ring developed by Steel City Testing Machines Inc., 8817 Lyndon Av., Detroit 38. Scales are graduated to 20 millionths of an inch. Tension or compression loads greater than 200,000 lbs can be measured.

A completely automatic means of weighing containers and marking the weight on them is being made available by the Wilson Automation Co., 27107 Groesbeck Highway, Detroit 5. Speeds to 600 units per hour are said to be possible, depending on package size and range of weight.

INSTRUMENTS

Houston Instrument Corp., Houston 27, has developed a new device for determining specific gravity of solid materials. The instrument measures the pressure difference between two air cylinders, one containing the sample, when the air in each cylinder is compressed by a piston. Specific gravity of irregular shapes or porous materials is difficult to determine by simple techniques.

COMPUTERS

An electronic computer will take over the the manufacturing control job at the world's largest synthetic rubber plant in Houston, according to Goodyear Tire & Rubber Co., Akron, Ohio. Instruments will feed data to the computer, which then will control temperature, pressure, and rates of flow as desired for the formula of rubber being made. The computer was built by Goodyear Aircraft Co.

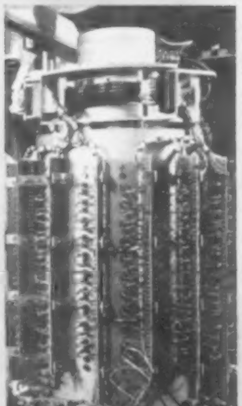
Unusual versatility in an analog computer is claimed for the DYSTAC computer made by Computer Systems Inc., Monmouth Junction, N.J. Short-time accuracy is ±.05%.

Problems with sequential parts can be solved with the computer. For example, in distillation calculations, computer components can be time-shared to control a process unit, bringing it on stream, running it, removing the charge, and shutting down the unit.

Applications include the design of optimum instrument control systems, structures, heat exchangers, catalytic convertors, and the solution of many analysis problems important in refining operations.

The Univac III computer system has been announced by Remington Rand Div. of Sperry Rand Corp., 315 Park Av. South, New York 10. The computer has all solid-state components, and uses printed circuit units similar to those in the company's giant Larc computer. Feature of interest in the Univac III is that the computer is instructed by typewriter using English words rather than code symbols!

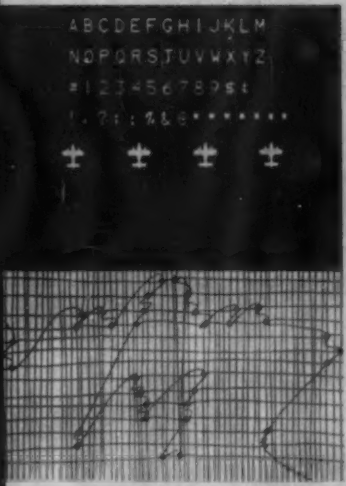
Air-traffic computer



◀ A large solid-state computer for air traffic made by Librascope Div. of General Precision Inc., 92 Gold St., New York 38, is being tested by the Federal Aviation Agency, It is the key element of a new data-processing system to improve coordination from takeoff to touchdown of civil and military flights.

Air-traffic control is performed chiefly by nationwide network of approximately 13,000 traffic controllers who handle clearance and control of flights. Traffic controllers must maintain safe separation between aircraft flying at widely different speeds and operating at different altitudes, and must merge air traffic into approach and landing patterns at busy terminals.

With the new data-processing equipment, controllers will be able to enter manually or automatically into the computer a variety of flight-plan information such as time and place of flight departure, destination, and flight route. Computations will be made and information presented to appropriate controllers automatically through an array of display consoles designed to be read easily.



Electronic printing

◀ Development of an electronic device which makes possible ultra-high-speed reproduction of characters and pictures with the quality of fine printing was disclosed by the Columbia Broadcasting System, 485 Madison Av., New York 22. The device, called VIDIAC (Visual Information DIsplay And Control), produces numbers, characters, and symbols on the screen of a cathode-ray tube.

The symbols are generated electronically instead of with metal type fonts or graphic originals, which have been used previously. Individual characters or groups of characters are supplied as plug-in elements in the data-processing system.

A network of commercial computers able to communicate with each other by microwave and telephone wires has been demonstrated by Rocketdyne Div. of North American Aviation, Canoga Park, Calif. Data on design, tests, budget status, and production status have been transmitted between two divisions.

CHEMICALS

An antiknock agent to replace tetraethyl has been introduced by California Research Corp., a subsidiary of Standard Oil of California, Richmond, Calif. The agent, called tetramethyl lead, is said to provide a higher octane rating. In modern engines, tetraethyl lead breaks down too soon in the combustion cycle, whereas tetramethyl lead does not.

New, low-cost chloro compounds with reactivity characteristics similar to benzyl chloride are being offered free in research quantities by International Minerals & Chemical Corp., Old Orchard Rd., Skokie, Ill. The four compounds--monochloromethyl alkylbenzenes, bis (chloromethyl) alkylbenzenes, chloromethyl methylnaphthalenes, and polychloro methylnaphthalenes--have possible applications in plasticizers, herbicides, fungicides, cosmetics, textiles, water repellents, pharmaceuticals, inks, paints, rubber, and many other materials.

Ion-exchange papers, consisting of fine-particle-size, ion-exchange resins, supported by cellulose pulp fibers, have been introduced by Rohm & Haas Co., Washington Square, Philadelphia 5. The papers are expected to have use in chromatography and filtering.

Conversion of carbon dioxide to oxygen is being studied at Aerospace Medical Lab, Wright-Patterson Air Force Base, Ohio. First, carbon dioxide and hydrogen enter a reaction, aided by iron as a catalyst, to form carbon and water. The water then is electrolyzed to form hydrogen and oxygen.

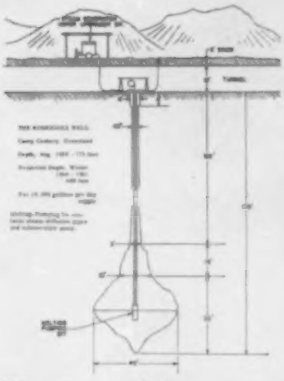
PROCESSES

A new process for making parts from aluminum powder by impact extrusion has been developed by Alcoa, 1501 Alcoa Bldg., Pittsburgh 19. The method is said to make possible production of parts with tolerances of .003 in., which cannot be made by other techniques.

Safer gun barrels can be made by winding fine glass fibers around a steel tube only 0.020 in. thick. The development is said to be the first basic change in design of gun barrels since 1900, resulting from five years research by Olin Mathieson Chemical Corp., 460 Park Av., New York 22. The process decreases weight and provides thermal insulation.

Color film for use in Polaroid Land cameras has been demonstrated by Polaroid Corp., Cambridge 30. However, the film will not be commercially available for sometime.

A technique for speeding up the arc welding of cast iron has been announced by Eutectic Welding Alloys Corp., Flushing, N.Y. The process uses a new electrode which makes deposits that can be quenched without danger of cracking. The need for slow cooling thus is eliminated.


Water from a glacier

◀ A system to provide large quantities of water for men living on a glacier has been developed by the U.S. Army Engineer R&D Labs, at Ft. Belvoir, Va. A three- to four-foot diameter hole first is melted into the glacier's dense ice layers. As melting continues, a bell-shaped cavity is formed and the water produced collects in a pool at the bottom.

During tests, a 42-inch hole was sunk to a depth of 140 feet in approximately 30 hours, using a steam generator made by Vapor Heating Corp., 6420 W. Howard, Chicago 48.

After 300 hours, a cavity 40 feet in diameter and 50 feet deep was formed to store 110,000 gallons of water. The water was brought to the surface using a submersible pump. Six and a half days after the steam was discontinued, the well was found to contain 1,000 gallons covered by a two-inch layer of ice.

SPACE AND MISSILES

A crossed-field acceleration test facility prototype is under development at Allis-Chalmers Mfg. Co., Milwaukee 1, to impart additional acceleration to a plasma stream in hypersonic wind-tunnel tests. The crossed magnetic and electric fields have provided energy increase of 60%.

Batch production of solid rocket propellents can be replaced by a continuous process, according to the Longhorn Div. of Thiokol Chemical Corp., Marshall, Texas. The process is expected to give better propellent uniformity with increased safety and economy. It also makes possible more efficient loading of rocket cases.

Battelle Memorial Institute, Columbus, Ohio has developed an airborne optical beacon with a precisely timed flash that can be photographed at distances up to 400 miles. The beacon was designed to be carried in missiles to permit tracking them at night.

The light flash is rated at 50-million lumens, the equivalent of 10,000 50-watt bulbs. The flash is

produced in a quartz tube filled with xenon gas and containing two electrodes. A discharge between the electrodes is initiated by a 4,000-volt supply.

Miniature instruments record body functions.

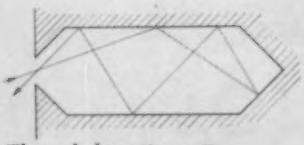
◀ Miniature instruments have been developed at Boeing Airplane Co., Seattle 24, to sense and record vital body functions in space. In one experiment, a man spent several hours in an air-tight chamber supplied by oxygen produced by growing algae (which converts carbon dioxide to oxygen). Algae may be the means for providing a balanced atmosphere for personnel during space flights. Other experiments involve the conversion of human waste to grow food.

A space communications system using solar radiation instead of radio waves for signal transmission is under development at Electro-Optical Systems, 170 N. Daisy Av., Pasadena, Calif. The system collects the sun's rays with a mirror antenna, sends them through a modulator for encoding information, and then to a second mirror system for transmission through space to the receiver.

Plans have been made for construction this year of six lighthouses powered by solar batteries by the Maritime Safety Agency of Japan. The first experimental lighthouse constructed last November has performed satisfactorily.

A thermionic generator tube can be used to convert heat from rocket exhaust gases directly into electricity, to operate steering controls and electronic equipment of the missile. Output of the generator is 270 watts, or nearly 80 watts per pound. It was announced by RCA and Hunter Bristol Div. of Thiokol Chemical Corp.

A gas-cooled mobile nuclear power plant is being developed by the Army and AEC. Goal is a reactor, with the mobility of a trailer-mounted diesel electric unit, that does not need a cooling water supply. The prototype will generate 400 kilowatts for one year before refueling is necessary.

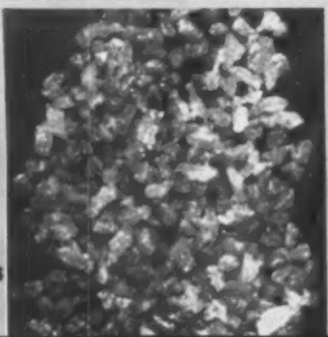


Thermal absorption unit

◀ A cavity-type thermal absorption unit for space-vehicle solar-power systems, with absorption efficiencies approaching that of an ideal black body, is proposed by Electro-Optical Systems, Pasadena. Radiation absorption efficiency is increased by multiple relections within the cavity, and a favorable distribution of energy over the internal surface is obtained.

MATERIALS

Man-made diamonds



◀ The first photograph of GE's man-made diamonds to be released shows they have very regular crystal faces, but are still more irregular than natural diamond fragments of equivalent size. They are used for grinding extremely hard materials. (General Electric Co., Detroit 32).


Glass "pillows" for filters

Corning Glass Works, Corning, N.Y., is producing tiny pillows and balls of glass for use as a filler and packing material and in filters. Hollow pillows can be used for light-weight structural support and buoyancy, and solid pieces can be used in tumbling processes.

Pyrolitic graphite for missile nose-cones and other critical applications has been developed at the GE Research Laboratory, Schenectady, N.Y. Structures are grown by decomposing methane gas and depositing the carbon.

The material can withstand extremely high temperatures and is stronger and more resistant to oxidation than ordinary graphite. It is intended for use in missile nose cones, nozzles and steering vanes, as well as for many industrial applications.

An interesting property is that thermal conductivity in one plane is up to 1,000 times greater than in another perpendicular direction. The material has been tested satisfactorily at temperatures to 6500 F.

New glass compositions

New glass compositions, some liquid at room temperature, have been developed by Bell Telephone Labs, 463 West St., New York 14. The glasses are composed of varying proportions of the elements arsenic, sulfur, and bromine. The new compositioins are stable in acids, but are attacked by alkalies. They have high resistivities and comparatively high indexes of refraction, between 1.9 and 2. Colors range from ruby red to light amber.

ELECTRONICS

The first gallium-arsenide transistor has been demonstrated by RCA, 30 Rockefeller Plaza, New York 20. The transistor can be operated at temperatures greater than 250 C, compared to 175 C possible with silicon transistors. Other characteristics of the new transistor are generally similar to those of silicon. They are expected to be commercially available within a few years.

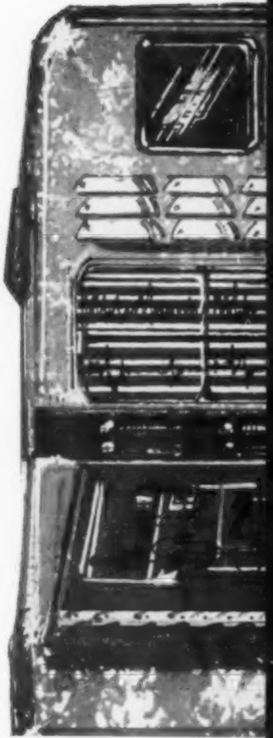
A tunnel-diode curve tracer has been introduced by Texas Instruments Inc., 3609 Buffalo Speedway, Houston 6. The instrument displays the forward characteristics of tunnel diodes made by various manufacturers.

High vacuums can be measured with a cold-cathode type discharge vacuum gage made by F. J. Stokes Corp., 5500 Tabor Rd, Philadelphia 20. Current between two electrodes of a gage tube gives a measure of the amount of gas present, and therefore the pressure.

PRODUCTS


Massive aluminum forging

A massive aluminum forging, produced by Alcoa, has been machined at Douglas Aircraft Co., to make a mandrel 12 feet long with a diameter tapering from 24 in. at one end to three in. at the other. The mandrel is used to make a nickel shell for the first major hypersonic wind tunnel. The mandrel was plated with nickel, then exposed to sub-zero temperatures to separate the nickel coating from the mandrel.



What Will Process Co

by **Leslie R. Driskell,** *principal instrument engineer, chemical plants divisi*

TWO DECADES AGO, chemical plants operated almost entirely with pressure gages and glass-stemmed thermometers were not uncommon. One decade ago, chemical plants used large-case recorders and pneumatic controllers. Many of the instruments were mounted near the process equipment because the operator had to be there anyway. Today is the era of the air-conditioned control room separated from the process. The operator no longer need stand by his equipment; he can operate more equipment more efficiently from the control center.

Where is chemical process control heading, and what form will instrumentation and control take in the near future?

Before exploring these possibilities, let us make a critical appraisal of today's apparatus. Certainly you may expect electronic transmitters, receivers, controllers, etc. to assume a major position in measurement and control.

But don't throw out your pneumatic instruments yet. They probably will be with us for a long time—at least as long as we have conventional instrument panels with their individual recorders.

Difficulty in electronics

Here are the problems:

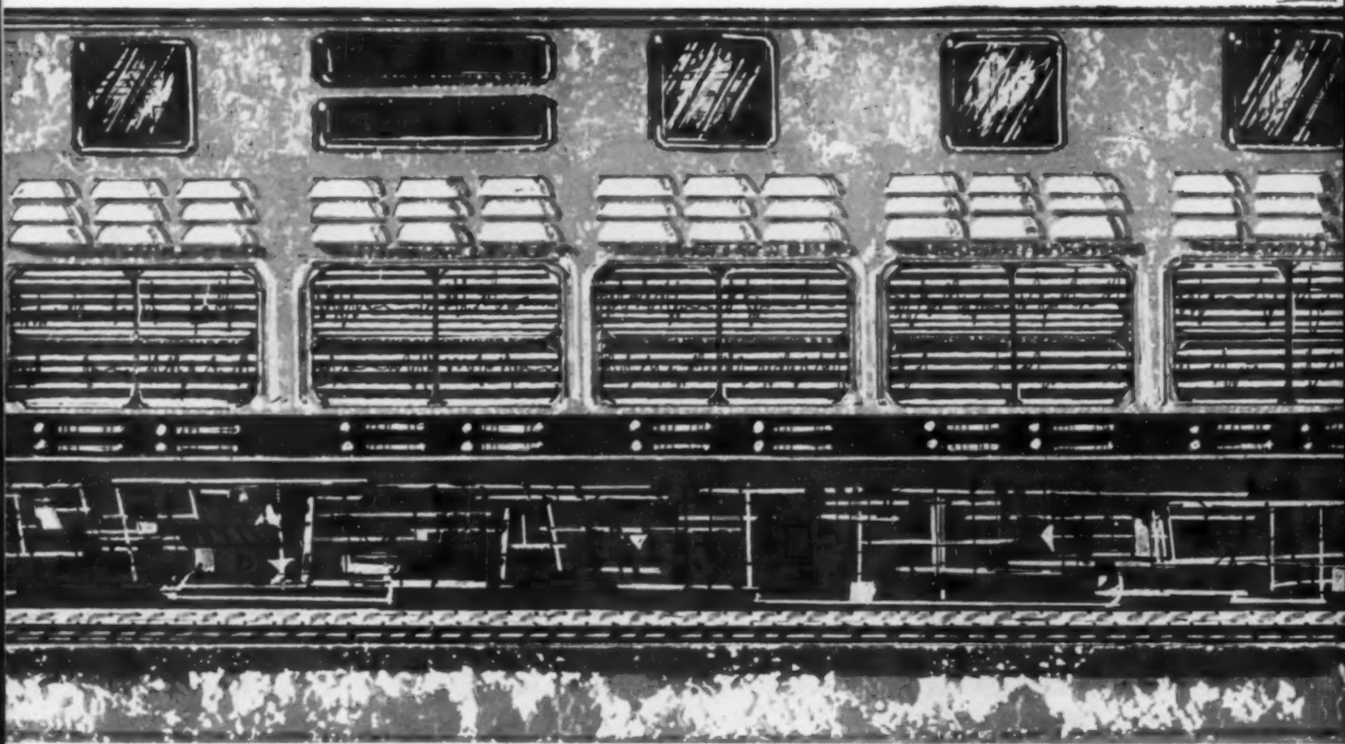
Electronic instruments still cost 25% to 40% more than pneumatic. Their chief advantages — superior dynamic performance and long-distance signaling—are required by few applications in today's processes. Long transmission lines common to the petroleum refinery usually are not found in chemical plants.

Since there is no standardization of transmission signals, various products are not interchangeable. This fact, along with the accelerated development going on in the electronics field, suggests that today's electronic instruments already are obsolescent. The second-generation electronic instrument is likely to differ radically from its progenitors.

Flow measurement is frequently a tough problem, particularly in the chemical industry. The magnetic meter is expensive when used to measure small flow rates, and is not applicable to all fluids. Most other types of flow-rate meters are messy; they're difficult to install and maintain, particularly when used for hard-to-handle fluids common in chemical plants. Measurement accuracy available is considerably less than needed.

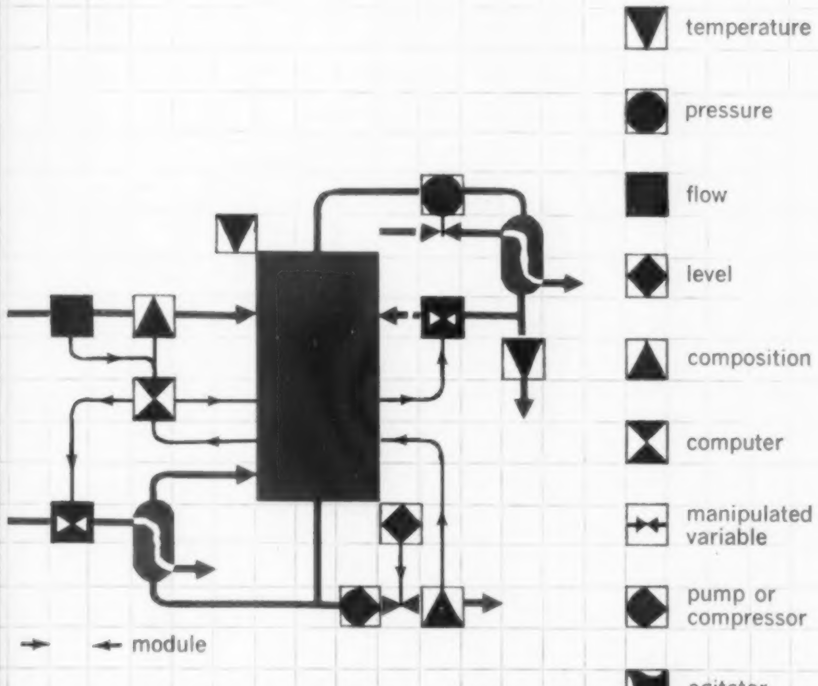
Totalizing or positive-displacement flowmeters, similar to the household water or gas meter, are

CONTROL CENTER OF TOMORROW *may be a console (upper right) built from standardized sub-assemblies. Analog readouts are given by cathode-ray tubes. To check any variable over the last three hours, the operator touches the graphic symbol for the quantity, and the information is projected on the screen. Switches can be used to select visual or audible signals. Section of the control console (right) shows how modular components can be arranged to provide a graphic display of the process.*



rols Look Like Tomorrow?

w-Knox Co.



As principal instrument engineer at Blaw-Knox Co.'s chemical plants division, Leslie Driskell is in charge of a 12-man instrument design staff. Averaging some 20-years experience per man, Driskell's group is exceedingly varied, working in chemical plants of every type as well as in petroleum refineries, jet and rocket engine test facilities, and nuclear reactors. Driskell is a senior member of the Instrument Society of America, and a past president of the Pittsburgh section.

used whenever a precise quantity of fluid must be measured. The reason for precision may be accountability, or the need for an accurately measured batch of process material. Development in these meters has been almost imperceptible since the passing of home-brew. While the needs of the petroleum refiner have been satisfied fairly well, the chemical engineer finds few fluids for which these meters are satisfactory.

Data-logging troubles

A few years ago data loggers were touted as a solution to the problem of information gathering and display for the control room. After numerous sad experiences by manufacturers and users alike, data loggers now have been relegated into the arsenal of instrumentation to be employed only where their use is justified. In the chemical industry the logger rarely can be justified except as a device for gathering data for research.

It was believed at first that data loggers would eliminate the need for recorders and reduce the size of control rooms. But several difficulties arose. Recorders were needed to capture the short-time variations of process quantities, which data loggers could not do. Reliability of the early data loggers was poor. In some cases, operation of the entire plant may depend on a single device, so failure of an electronic component may be very costly.

Today the chemical industry is considering computers for different process-control requirements. However, many companies are hesitating to use computers because of previous bad experiences with data loggers.

A lot more caution is being exercised this time to avoid misapplication. Monsanto, duPont, and B. F. Goodrich are the first in the chemical industry to undertake the required half-million dollar experiment. These companies picked processes where a cost advantage is probable, and they hope to profit by the *knowledge* gained from the effort.

In the light of our present technological development, what are the likely possibilities in the way of implements and methods which will be available to tomorrow's designer?

Our present needs for improvements will be met at least partially. New disclosures will reveal needs we didn't know we had. With the rapid development of solid-state electronics and the promise of new materials, anything can happen. Micro-miniature electronic devices will consist of encapsulated, plug-in sub-assemblies. Reliability will be astonishing by today's standards.

If, as expected, automated production of this equipment comes with micro-miniaturization, low cost will permit a high degree of redundancy, or duplication of equipment for better reliability. Built-in spares and self-monitoring circuits will reduce maintenance and improve reliability at the same time.

Tomorrow's control room

The electronic instrument of today is burdened by having been built like its precedessor. How will tomorrow's all-electronic control room look? Will it be an array of little boxes housing paper charts—the operator scurrying back and forth peering into little windows?

Will it be a typewriter hammering out rows of digits for hour after hour? Or will it be a gray hulk standing over in the corner humming quietly to itself, as it confidently and unerringly makes all operating decisions?

Someday, in some plants, this last picture may become quite common, but probably not tomorrow. We have a long way to go in design of the computer and the rest of the plant before this is possible. For most processes it is unikely that we can justify the fully automatic plant—neither the high cost nor the time required between the first dollar and the first delivery.

If we leave the human operator in the loop we should design our control center to take full advantage of his abilities. Present the information to him in a way which will be conducive to efficient decision making, and leave out unnecessary information. A little human engineering is called for here.

Man the instrument

We cannot have our human running around peering into little win-

Should the chemical-plant builder stick to the conventional, o

This article analyzes the problem and offers a realistic approac

dows, nor can we have him sit and stare at endless columns of numbers on log sheets. Man can compare numbers, but his digital storage system is small. If we give him readings frequently enough to describe the transients, he is unable to assimilate the information.

Man is similar to an analog, not a digital instrument. He has phenomenal flexibility. The response of the senses is almost universally logarithmic, enabling him to receive signals over exceedingly wide ranges with excellent discrimination.

The human ear can detect sound over a frequency range of almost 1,000 to one. Throughout 95% of this range it can resolve two frequencies which differ by only 0.3%. The amplitude ratio is amazing: several billion to one. Man's eye can receive light signals in the dimness of a starlit night and in the brightest sunlight, a range about equal to that of the ear. Perception is always logarithmic and analog in nature. It is apparent that the human operator can make best use of data presented to him in analog fashion and with logarithmic scales.

The human computer

Since there is no reason to provide our human computer with unnecessary information, we must store it until needed. We also will make use of machinery to scan and monitor incoming data and call any unusual matters to the operator's attention. Many simple routine decisions which the operator normally makes today could be made by small special-purpose computers or logic devices. These can be used 100% of the time and can surpass man in efficiency. Such devices will use standardized interchangeable components and will solve complex problems in mathematics.

Now, what does our control center look like? The "master computer" (the operator) sits at a comfortable console. Perhaps most of the console will be made up of cathode ray tubes or television screens, and also an intercom, knobs, buttons, and signal lights.

Analog data transmitted from the plant will be stored temporarily on magnetic discs or a similar device. Signals from controlled variables will be sent to the appropriate controllers. The output signals from these controllers then will perform their normal functions to maintain process equilibrium. Data needed for permanent record will be digitized periodically and either printed on log sheets for operating personnel, or re-transmitted to the accounting department by telemetering equipment.

An automatic monitor will detect any undesirable readings or suspicious trends, and operate an audible alarm, perhaps even play a recorded verbal message. The operator then may elect to see records of any pertinent stored analog data. In an instant these data can be shown on one of his screens.

The operator may choose to observe machinery, look into vessels, or inspect conveyors by closed-circuit television without moving from his chair. He can listen to the sounds of his moving equipment on the intercom. If assistance is required he can use this sound equipment to summon aid quickly from other operating or maintenance personnel.

The description may sound fantastic, but remember it is all technically feasible. Most of the hardware is now available, but must be adapted to instrument use. The control center designed around the human operator permits him to make maximum use of his decision-making ability. It is compact and not excessively expensive.

New control devices

We will leave this futuristic control center now and see what's taken place in the plant and in the black boxes occupied by control equipment. Transmitters will be smaller, faster, more rugged, and more precise. Solid-state physics soon may bring entirely new, more versatile, and more dependable devices.

For example, Hughes Aircraft has announced a solid-state ionization chamber no larger than the head of a pin. Said to be capable of measuring the number and energy level of atomic particles better than conventional detectors, the output signals of its transmitters will be standardized so they'll work with each other and with universal controllers and transducers.

Tomorrow's electronic controller will be small, stable, and reliable. It probably will be racked up in a cabinet with the other plug-in subsystems of the instrument complex. When failure does occur it will be discarded and replaced by another controller pre-set to the adjustments required for the specific process loop.

Electric valve needed

The pneumatic control valve actuator will be difficult to replace. One of the most reliable pieces of moving equipment in the chemical plant, it is inexpensive and can be made as precise as necessary. In power, speed, and size it is hard to beat. The electro-hydraulic actuator is faster, but cost limits its use to the most demanding applications.

Nevertheless, if electronic instruments ever are to offer any important advantage over pneumatic instruments, the pneumatic-valve actuator must be replaced in spite of all its advantages. Why? Because pneumatic actuators require the expense of a compressed-air system with its compressors, dryers, piping, and filters.

To compete with the pneumatic actuator, any electrical actuator must perform useful work at rates up to one horsepower. It must be capable of being positioned with an accuracy of 0.1% using a low-level control signal. The cost should not exceed that of the pneumatic actuator. The feasibility of accomplishing this task with the electric motor drive has not yet been demonstrated. Hydraulics simplifies the design problem somewhat, but lacks desirable properties of the pneumatic valve, particularly with respect to cost.

The control industry is searching for new techniques to solve the actuator problem. A unique thermo-drive actuator marketed by Swartwout Co. employs Freon vapor pressure generated by a continuously powered electric heater. The positioning pilot regulates Freon vapor flow to an integral condenser. The actuator is simple, but lacks speed.

For instance, to duplicate the biological marvel of the grasshopper's

apfrog ahead into the instruments of tomorrow?

or chemical-industry management.

jumping muscle, a quarter-pound actuator would have to deliver 5,000-lbs thrust. Possibly man-made chemical muscles can be made to store and release useful mechanical energy on demand.

Chemical muscles

Considering advances being made in polymer chemistry, such an idea is not at all fanciful. Simple machines of this type have been built recently at the Weizman Institute of Science in Israel. Polyacrylic acid and polyvinyl alcohol linked together were used as the muscle material. In the quest for tomorrow's actuator, the instrument designer may well find the answer in the chemical research laboratory.

Much of today's instrumentation will not disappear for some time to come. However, much more can be expected in the way of standardization. The Instrument Society of America is working on many standardization projects to become effective in the near future. As noted earlier, system design or dynamic analysis is one of the new techniques used by the chemical-plant control engineer.

The need for such analyses should increase as faster processes come along and larger flow rates are used. Without such studies the over-design required is economically intolerable. In some situations the control of a process actually may become impossible.

It is important, therefore, that process and instrument engineers be provided with and taught to use equipment necessary to make dynamic analyses. Analog computers are most suitable for this purpose. In the very near future they are certain to become standard equipment for chemical-plant designers.

As cost of labor and materials continues to rise, more and more engineering hours will be spent to design plants using less material, less construction labor, less maintenance, and fewer operators. For example, assume that an around-the-clock operator costs about $25,000 a year, including fringe benefits and overhead. How many engineering man-hours at $10 an hour are justified to reduce the number of operators by one? Even 2,500 engineering man-hours can be recovered in a single year.

Management's dilemma

We are now in the midst of a furious technological expansion. The pace of development seems to quicken monthly. Management frequently is faced with making decisions in matters where the nature of the problem is changing continually.

In the chemical industry this situation presents a particularly tough problem because technological progress often places management in a squeeze. A large portion of today's sales come from items which did not exist a few years ago. In the field of instrumentation, more than half of the process instruments available today were not on the market 10 years ago.

So a decision to build a new plant involves the questions: "How much of the market can we count on?," "How automatic should the plant be?," and "Will something come along to displace my product entirely?"

The second question, how automatic the plant should be, concerns us here. The problem is different from classical ones appearing in textbooks on economics, where costs are simply balanced against an anticipated return. The problem is superdynamic rather than static. Our parameters are changing so rapidly that *time* is now the first consideration.

PROGRESS IN DESIGN *of instrument panels has been dramatic. Ten years ago the panel above was a modern installation. Instruments, piping, and wiring were installed in the field next to the process equipment. Seven years ago, the central control room below was typical. Although a vast improvement, the cost was high for running miles of metal tubes between the panel and the process equipment. Pneumatic controls are cheap, reliable, and precise. But they have to go. They require too much auxiliary equipment.*

Examine at least three types of problems: a new process, a new plant for an old established process, and a new look for an old plant.

For the first problem, the research department of a medium-sized chemical manufacturer, we'll assume, has come up with a new substance called "hexafluorogoop." Market research is convinced that within five years it can capture 50% of the market now held by "dichlorogoop," if the sales price can be held to 90 cents a pound. However, a competitor working on a similar development could be a serious factor in the market if he were successful.

Spending time

Now here's what makes it tough. Spending the time necessary to get the most efficient production plant and achieve a good competitive position means missing opportunities entirely. We cannot even afford to spend too much time in reaching a decision. On the other hand, a plant sufficiently efficient to keep production cost to a minimum may be squeezed out in a year or two anyway and the venture will not be profitable.

Here are some of the possible alternatives:

- Build a pilot plant to develop the most efficient process. Try out equipment which promises to improve product quality. Gather all the data which might be needed to make a systems study for the design of the main plant.
- Build a semi-works — possibly after the pilot plant has proved out, or at the same time. It even may be built instead of a pilot plant. Building both plants at once will allow penetrating the market while the pilot plant is generating data for the main effort. This method, of course, is costly.
- Take a chance and design a full-scale plant. Some inefficiencies will be inevitable. Re-design may be high; over-design is to be expected; field changes probably will be required. Even so, to recover the investment in about two years, it could be justified economically, especially since the cost of a pilot plant and perhaps a semi-works is saved.

Once hard-pressed management makes its decision, how does it affect the instrumentation and control picture? In each of the three courses outlined above the point finally was reached where the main production plant is ready to be designed, but the method of attack is different.

The pilot plant provides a sound basis for design of the main facility. Temperatures, pressures, and flow

rates are all firm. Heat-transfer coefficients, operating characteristics, and corrosion problems are narrowed down.

But equipment can't be performance-scaled up this much and not provide some surprises. More disconcerting is the control problem, because time constants are significantly different in the two plants. Variations in layout introduce wide differences in dead time (time required to move material or signals from one place to another in the process.)

Consequently, dynamic data taken on the pilot plant usually has little value when extrapolated to the production-size plant, and for this reason it rarely is gathered.

An ability to construct a mathematical model of the process is enhanced only slightly by information on the dynamics of the pilot plant. Usually the information is not sufficiently valuable to justify taking the time to compile it.

How can modern technology be utilized to the best advantage? In the pilot plant, strive for flexibility of design. Use pre-fabricated modular-type instrument panels, adjustable range force-balance transmitters, miniature pneumatic instruments with interchangeable components, plastic tubing—and if warranted by the amount of data needed—a data logger.

Don't stint on instruments

Don't stint on instruments in the pilot plant—information is the principal product. If the pilot plant can't be made to work, it is a total loss. Most important, since time is vital, utilize a top-notch team. There is no substitute for experience at this stage of the work.

If it is decided to "shoot the works" and scale up from laboratory to full-blown plant, the instrumentation picture differs little. The main plant is now a pilot plant and needs the same flexibility.

The plant layout and scheme of operation must be examined carefully because economy of operation is much more important. More remote control is indicated. Measurement points should be provided to gather data for system studies to improve the plant after production begins. These data are also useful for designing plant No. 2 when the time comes.

The second problem is where production facilities are to be expanded by building a new plant for an old established process. A lot of engineering time can be saved by building a copy of the old plant with a few bothersome features revised. The overcautious designer may feel that this is less risky. Usually this approach means that the owner is stuck with a "new" 10-year-old plant already obsolescent.

Management should plan sufficiently ahead to get a greatly improved plant. Modern design often can pay for itself in construction and start-up costs alone. Continuing profits of optimum design are reflected in lower operating and maintenance costs, less downtime, and better product quality.

A truly attractive prospect is a new look for an old plant. Modernization of a 10- to 20-year-old plant can produce more profit per dollar expended than any other investment.

If the product needs upgrading, if a little more production is required, if operating costs are excessive, and if the profit margin is being squeezed, you may be surprised what modernization can do. An integrated study is necessary. Process kinetics must be ascertained by dynamic testing. Armed with these data, control and process engineers frequently can remold the process to a thing of beauty: profit. ■

Analysis Instruments —Key to Process Controls

Infrared and chromatograph analyzers have replaced crude instru
precise control of chemical processes. Now needed are in

by **Marvin D. Weiss,** *section head, special instrumentation division, Union Carbide Olefins Co.*

NOT LONG AGO, only pneumatic instruments were allowed in a chemical plant. The presence of combustible gases and vapors was a deterrent to the use of electrically operated instruments. With improved techniques in building non-hazardous instruments, electrically operated analysis instrumentation now penetrates even into plants operating with highly combustible gases. Computers, data-handling systems, and electrical controls are accompanying the analysis instruments.

Analysis always has been the key to control of a chemical process. Chemical products — metals, paper, glass, petroleum, petrochemicals, and gases—have a value based upon their chemical purity. Previously, purity was determined in the laboratory by chemical analyses of batch samples. When product was "off-spec," adjustments were made in pressures, temperatures, and other operating parameters.

Now analysis is performed by instruments which continuously monitor the processes themselves. Continuous samples are taken of the product, and the operator knows immediately if any change in product quality occurs. Analysis instruments adjust the settings of instruments controlling the temperature and pressures.

What's behind the phenomenal change from laboratory "instrumen-

COILED GLASS TUBING, *by Corning Glass, was developed in 300-ft. lengths for gas chromatographs, one of the analysis instruments.*

...s for gas analysis, and have made possible

...ents that are both simple and fast.

...al analysis" to continuous "analysis instrumentation" at the process unit?

Ten years ago in the soap industry, pH electrodes continuously monitored the acid content of liquid streams. Around gas plants, hot-wire filaments monitored the atmosphere for explosive hazards. Cooler wire filaments operated as "katharometers" to measure thermal conductivity of gas mixtures.

A few specific chemical methods automatically added reagents to a process stream and monitored a change in color, or used another instrumentally detectable effect. But no single analyzer could be mass produced and used in many different applications.

Infrared analyzers: 1st stage

Then, almost simultaneously, three or four instrument companies felt that continuous-process infrared instrumentation was the key to the analysis of gas mixtures. In 1952, Baird, Perkin-Elmer, Liston-Becker, and Mine Safety Appliances, followed soon afterwards by Leeds and Northrup, all introduced process infrared analyzers.

It was natural for infrared to be the first major field of effort for analysis instrumentation, especially for organic systems. In the laboratory, infrared methods of analysis were replacing many arduous wet-chemical methods.

The utility of this method depends upon the uniqueness of infrared absorption characteristics of each organic molecule. Given a library of such reference spectra, the infrared spectroscopist can identify any pure component present in a sample.

In addition to making use of infrared as a method of laboratory analysis, Karl F. Luft, in Germany, and A. H. Pfund, in the United States, during World War II had worked out techniques of infrared analysis that were uniquely satisfactory for plant-stream analysis.

Why are plant analyses so difficult?

Difficulties arise in plant-stream analyses because materials change with time in concentration and even in nature. Occasional impurities appear and changes in background components take place. The process analyzer must operate continuously, out of doors, in a corrosive atmosphere—not in an air-conditioned, temperature-controlled laboratory.

Process infrared analyzers not only must cope with gross changes in sample composition, deposits of dirt, and polymerizing material on the optical surfaces, but also with gradual drifts in the analyzers' electronic measuring systems.

Laboratory analyzers are monochromatic—they utilize only one wavelength of light for each measurement. A spectrum of a material's absorption of infrared light over a range of wavelengths is taken point-by-point, one wavelength at a time.

Process analyzers use the *entire band* of infrared radiation generated by a hot-body source. A gas sample is used to filter out those frequencies characteristic of components present. The detector is made to respond to frequencies removed, and especially to frequencies possessed by the one component sought.

Thus, infrared analyzers have to be designed so that response to the

component sought is many hundred times the response to other materials which may be present in a gas sample.

The two types of infrared analyzers developed are called the positive, or Luft type, and the negative, or Pfund type, as illustrated by the diagrams at right.

The Luft analyzer

In the Luft-type analyzer, infrared radiation passes through two cells. A sample cell contains a continuously flowing gas mixture to be analyzed, including *gas X* (see diagram), the one to be measured.

The other, the comparison cell, contains all components of a sample stream, except the one component to be measured. As infrared radiation passes through the sample cell, gas X absorbs the characteristic wavelength of the component to be detected and the other gases absorb characteristic wavelengths of the other components.

In the comparison cell, absorption of radiation takes place at wavelengths for components other than the one being measured.

The light is chopped by a rotating blade or mirror so that it alternately passes through the sample cell and the comparison cell. Each resulting beam is made to impinge upon a window of the detector. A gas is sealed in each side of the detector behind this window, and its absorption is similar to that of the gas (gas X) to be detected. (It usually is the gas to be detected itself.)

Infrared radiation falling upon component X in the detector is rich in radiation due to X on the comparison side, and lean in radiation due to X on the sample side.

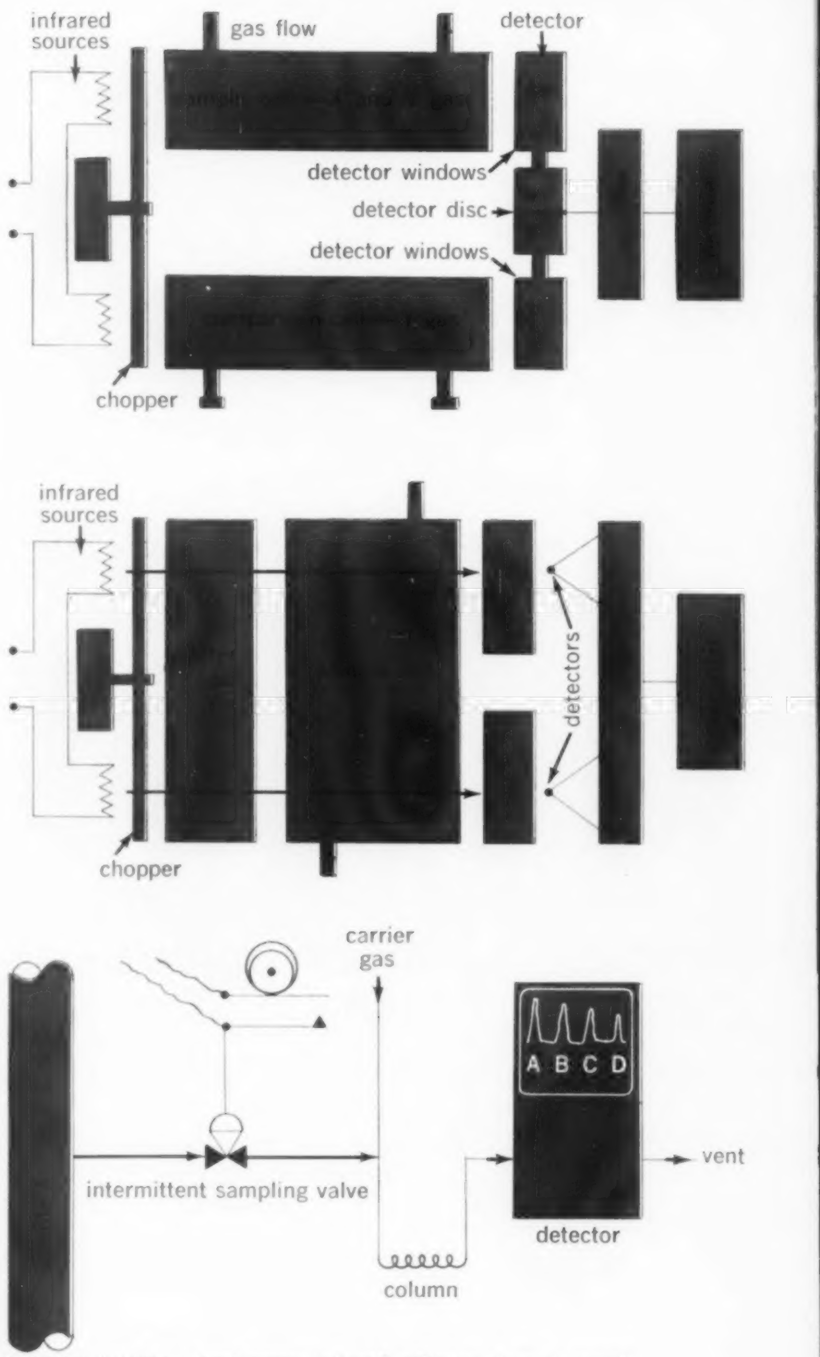
When the gas in the detector cell absorbs the radiation, it expands; when it does not receive this characteristic radiation it does not expand. The two chambers containing the detecting gas are separated by a flexible microphone disc. As the gas expands the disc vibrates, and its amplitude of vibration is proportional to the amount of gas to be measured.

The vibration then is converted into an electrical quantity and amplified.

The Pfund analyzer

The Pfund analyzer uses two infrared beams and two detectors, with a gas sample cell in the path of both beams.

Gas X again is to be detected. A cell containing gas Y (the gas not to be measured) is used to filter out infrared radiation corresponding to gas Y, in order to increase sensitivity of the system.



LUFT-TYPE ANALYZER *(top) passes infrared radiation through sample and comparison cells. Absorption of radiation in the sample cell depends on the quantity of gas X, to be measured. Detector measures different radiation in the two paths.*

PFUND-TYPE ANALYZER *(middle) absorbs part of radiation corresponding to gas X in the sample cell, common to both paths. Cell containing gas X absorbs, and cell with gas Z passes remaining gas X radiation. Detectors measure difference.*

GAS-CHROMATAGRAPH ANALYZER *(bottom) injects a sample of the gas to be analyzed into the carrier gas stream. Passing through the column, some gases are retained longer than others. The detector measures each component as it emerges.*

The two beams pass through the sample cell in which part of the radiation corresponding to gas X is absorbed.

Finally, the two beams pass through two filter cells before reaching the detectors. One filter cell contains the gas to be detected, gas X, and does not allow any of its radiation characteristic to pass through.

The other filter cell contains gas Z, which does not absorb any of the radiation characteristic of the gas to be detected. Thus, radiation corresponding to gas X passes through the Z cell and reaches the lower detector, the amount of radiation depending on the quantity of gas X in the sample.

The difference in the radiation reaching the two detectors depends upon concentration of gas X in the sample. An electrical signal from the detectors then is amplified and recorded

Difficulties with infrared

Infrared analyzers were popular in the early era of analysis instrumentation (1950 to 1955), and many chemical firms, including Dow Chemical, American Cyanamide, and Texas Butadiene & Chemical, developed them for specific purposes.

Although based on sound scientific principles, infrared analyzers just didn't work out in the process plant. They were complex electronically and required maintenance by skilled technicians or physicists. The optics eventually provided trouble due to changes in composition of process streams, and only an experienced spectroscopist could diagnose difficulties and repair them. Another major drawback was their cost—often as much as $10,000 to $15,000 without installation.

Process chromatography

In 1955 the chromatograph appeared as a solution to the analysis instrumentation problem. Chemical and petroleum companies found that a plant-stream chromatograph would operate continuously with little trouble. One chromatograph could analyze for many components, whereas the infrared could measure only one.

Chromatography simply means "colored pictures." In 1906, a botanist named Tswett was trying to separate the pigment in leaves. He dissolved the pigment in a solvent and poured it into a glass column filled with an adsorbent, whereupon the pigment was retained in a series of colored bands.

Tswett carefully broke the glass tube into sections, keeping each colored band in a separate section. He

U.S. leads U.S.S.R. in gas chromatography

▪ U. S. industry is way ahead of Soviet industry in gas chromatography, according to Dr. Robert L. Pecsok, a chemist at UCLA.

Pecsok inspected chromatographs and other instrumentation equipment at a recent exposition in Moscow. Russian equipment appears to be copies of models available in other countries about four or five years ago, and is not of the best quality.

Soviet scientists admitted they had been unable to equal claimed performance of U.S.-built gas chromatographs. There appear to be few Soviet investigators working on chromatographs, but they are very active.

Pecsok points out, however, that he is not certain how accurate a picture he obtained, because he had to base his judgments largely on publicly displayed instruments. ▪

Marvin Weiss became active in analysis instrumentation in 1950, just as it started a major revolutionary growth. He has participated in this growth as R&D manager of several instrument companies and, now, as section head of continuous analyzer development activities for Union Carbide's special instrumentation division. By education, Weiss is a chemical engineer, mathematician, and physical chemist. He introduced the field of reactive photometry at the Taller & Cooper Co., developed a catalytic analyzer for Fisher & Porter Co., and now is developing new techniques for analysis instrumentation at Union Carbide.

then could re-dissolve each separated material and have a relatively pure specimen of each biochemical substance sought.

In 1941, Martin and Synge, engaged in the separation of amino acids in chloroform and water, invented partition chromatography. They were separating their materials using an automatic multiple extraction with chloroform. Mainly to avoid chloroform's toxic effects, Martin began to think how they could use a modification of Tswett's apparatus to effect their separation.

If the liquid solvent (water) could be retained on the surface of a solid adsorbent (silica gel) and the mixture, dissolved in chloroform, poured into the column, the soluble components would be retained more than the others. Within a few hours, the column was prepared and its success demonstrated.

"Gas-liquid chromatography" was used in 1952 when James and Martin separated components of volatile fatty acids. The volatile acids were carried through the column in the vapor state by a carrier gas (nitrogen). As the acids passed through the column, they were separated from each other by their varying solubility in the liquid on the surface of the solid support.

They appeared in the form of "peaks" of material. The peaks were detected by bubbling the output gas through a colored solution of an acid-base indicator and continuously titrating this solution to a fixed color, as measured with a photoelectric cell.

The method for detection of the separated peaks corresponding to components of the sample was suggested by Martin—the use of the thermal conductivity "katharometer." If hydrogen or helium is used as a carrier gas, the presence of another component in the mixture causes a great change in thermal conductivity.

The thermal conductivity of a light gas is much higher than a heavy gas. Thus hydrogen, being the lightest gas, conducts seven times as well as air. Freon has a thermal conductivity about one-fifth of air. Light molecules are more mobile than heavy ones and conduct heat more rapidly.

Gas-solid chromatography

In gas-solid chromatography, a solid adsorbent such as activated charcoal is the column material. A carrier gas continuously flows through the column and through the detector, or katharometer, which is connected to the exit end of the column. Usually the katharometer is

connected into an electrical bridge circuit. (See diagram, page 58.) A valve automatically injects a sample of the gas to be analyzed into the carrier gas stream at the proper time.

The sample containing a mixture of gases is carried as a whole into an adsorbent column. As the sample enters the column, some of the components are retained by the adsorbent more than others.

Those components that are lightly retained readily re-vaporize into the carrier gas stream after a short time. Those that are firmly retained reenter the carrier gas stream after a longer time.

Each component emerges from the column distributed over a time interval, but at one instant the concentration of the gas component is at a maximum. The time at which this maximum occurs identifies the component, and the magnitude of signal at the detector determines its concentration.

Gas-liquid chromatography

In gas-liquid chromatography, the liquid is a solvent that has greater affinity for one component in the gas mixture than for any other. A thin film of liquid is coated upon the surface of very small particles of an inert solid support.

A column consisting of a three-foot length of quarter-inch aluminum tubing, for example, is packed carefully with coated firebrick. The packed column is attached to the reference and detection katharometers just as with the gas-solid column. Operation is similar to that of the gas-solid column.

The chromatograph is a *separating* device. It separates adhering gases from the less adhering. On charcoal, it separates gases in accordance with their molecular weight. It can separate component gases which cannot be separated by boiling.

The time for a gaseous peak to emerge beyond the time of the fixed (non-adhering) gases is called the *retention time*. Knowing the retention time and nature of the material, the location of its peak can be determined.

In process analyzers, composition of the feed to be analyzed is usually known. The concentrations of one or more components need to be determined and continuously monitored. Hence the process chromatograph can be "zeroed in" on one or more of these peaks for monitoring.

In most process instruments a bar-graph display is used. The height of the desired peak is calibrated in terms of concentration of the ingredient to be measured. As the peak emerges, a switch turns on a recorder and leaves it on until the peak has passed its maximum. The recorder paper does not move during this period, and thus the peak appears as a bar on the paper.

Often a series of four or five components are monitored in this way. When the cycle is started again a double space is made between cycles, so that the location of component number one again can be noted.

Although these procedures lead to complexities, they provide economic value to the analyzer. One $6,000-chromatographic analyzer may perform six analyses in one operation (at a cost of $1,000 per analysis). One $6,000-infrared analyzer (they sometimes cost as much as $12,000) can perform only one analysis.

"Someday I'll throw out this thing and buy me an analyzer."

An analyzer in your future

Now that the process industries have become analyzer conscious, they are bound to recognize applications for the old types of analyzers as well as develop needs for the new.

The first analyzer in a plant is a contagious thing. At first its analyses are doubted. The gas analysis performed by the analyzer to the nearest 10th of a per cent is checked with an Orsat analysis accurate to the nearest per cent.

The analyzer that continues to read zero when the operator "knows" the plant is producing is called "dead" (or other names). The analyzer that indicates a fluctuating product when pressures and temperature recorders show constant conditions is called "crazy;" "it's measuring something else," etc.

Eventually some crisis takes place in the process and the analyzer helps the operator. His Orsat analyses were incorrect; the analyzer was right all along; his process output does fluctuate as the analyzer's record indicates.

Shortly afterwards, operators are controlling their process only by the analyzer. They ask for more analyzers to control additional parts of the process. Operators of adjacent units talk to our new-won disciples of process analysis during a coffee break. Soon all adjacent units are calling for analyzers. Within a short time, there is an analyzer in every unit in the plant.

This logarithmic spiral reaches a plateau and then a new cry is heard: "We need better analyzers!" If the analyzer is monitoring impurities at a 1% level, the call is for an analyzer that will monitor impurities at a 10th of a per cent. The operator is learning how to control his process better, producing a high-quality product.

A year later, 0.1% is not enough, he wants a trace analyzer to monitor 1/100 of a per cent or 100 parts per million. Now the cry for greater sensitivity has spread to the point where detectors are being developed to detect one part per billion. And there is talk of detecting one part per trillion!

Greater sensitivity equals higher speed

As a violinist develops in skill and talent he learns two things: to play on pitch, and to play faster.

Similarly, the request for greater sensitivity of analyzers means our industry is learning to operate closer to absolute pitch. The development of greater agility has provided a request for greater speed of analysis.

The chromatograph proved itself economical because it could measure many components and many streams. But, in so doing, it had to be slowed down. If a chromatograph analyzes one stream in 12 minutes, it takes 36 minutes to analyze three streams. Work is being done with faster chromatographs: capillary columns provide high-speed separation; miniature detectors provide high-speed measurement.

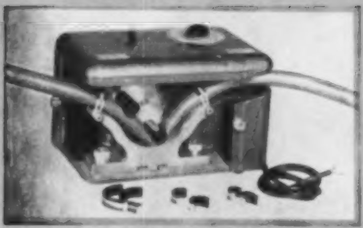
Because of their continuous operation and consequent faster speed, low-cost infrared analyzers are again popular on the market. But they do not respond to a change until the new sample has entered the sample cell. Smaller and smaller sample cells are the solution.

Unless a radical new discovery is made of an analytical technique that is simpler than the chromatograph and more rapid than the infrared analyzer, these two basic instruments appear to be the foundation of analysis instrumentation in the process industries for some years to come. ■

trendletter (continued from page 47)

BTU meter for assessment of heating or cooling costs has been developed by Air Conditioning Equipment Corp., 219 E. 44th St., New York 17. The meter measures volume or weight of the heating or cooling fluid and determines temperature difference between fluid entering and fluid leaving the system. These data give the quantity of heat removed or added.

Telex Inc., 1633 Eustis Av., St. Paul, has introduced a novel hearing aid. A tiny transmitter, located in the bows of the wearer's glasses, receives sound and transmits it without wires to a receiver in the ear canal. Transmitter frequency is 200 kc, below the broadcast band. The transmitter has five transistors and the receiver has one. Each has a battery.



New-type pump

◀ A pump made by Schuco Scientific Div. of Schueler & Co., 75 Cliff St., New York 38, utilizes a flexible hose on a curved track. The material being pumped is forced through by moving rollers across the hose.

Sincerely,
INDUSTRIAL RESEARCH

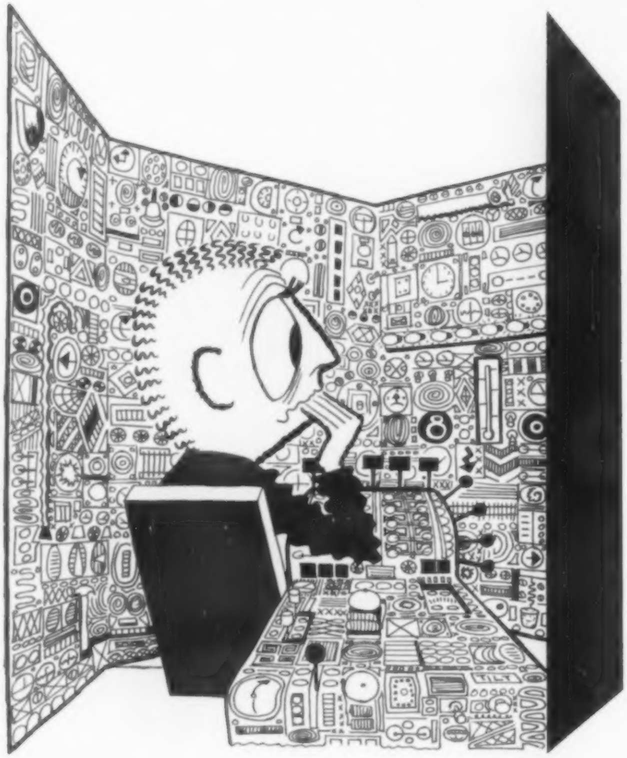
Harold Garbarino

technical director

P. S. I·R has received word that "fundamental research, by . . . definition, is a broad field of inquiry. There is much, for instance, that is not yet understood about the seemingly simple subject of shaving. What exactly happens when a whisker is cut by a sharp edge?" (Anyone?) "What are the intricate interactions between the microscopic structure of hair and that of metal? Detailed answers to questions such as these . . . will be the basis for future advances in shaving . . . A new research lab to house the world's leading group in shaving research has just been opened." According to a spokesman, "the new building will give the scientists room to stretch their imaginations."

"Punched cards, used by the billions in business and governmental operations, can now be computed, edited, and punched . . . on both sides in a single operation," using a system announced by a major manufacturer of computers.

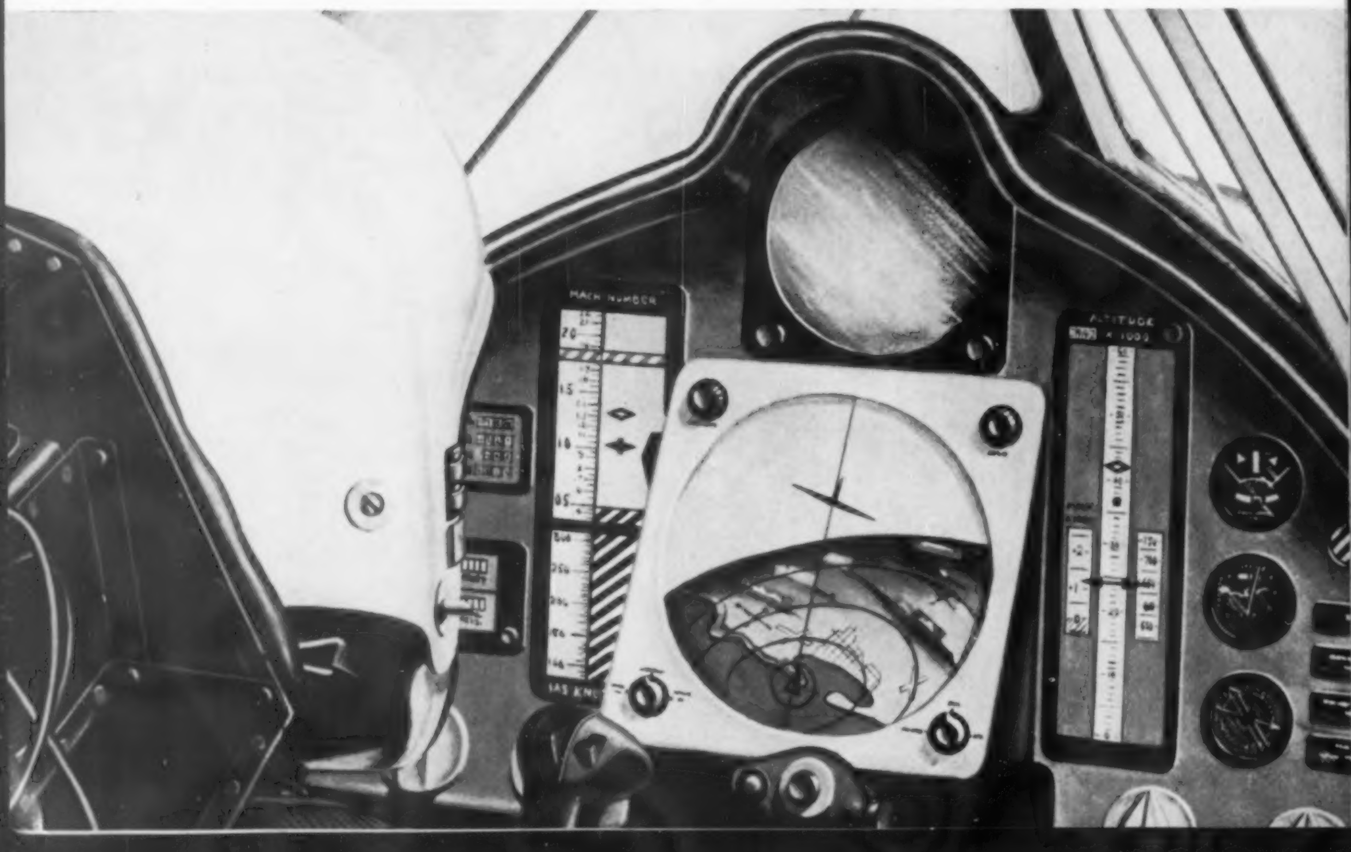
"Dear Friend: To help you build your most valuable business asset, good will, we offer our helpful book, 'Good-Will Messages and Letters' . . . We are going to give you an opportunity to buy 'Speeches for Every Occasion' at a special price if you purchase either 'Good-Will Messages and Letters,' 'Little Stories,' or 'Punch Lines.' Every speaker should have 'Little Stories' to provide spice and pep for each talk or remark . . . You can make an entire speech with the right little stories to provide all the facts, humor, punch, and pep you need."



Aircraft cockpits have to be simplified. Distractions must be eliminated while at the same time giving the pilot more information that he really needs. Neither the 'outside-in' nor 'inside-out' method for displaying the aircraft

REVAMPING the 'Clock-Shop

by **Lawrence J. Fogel,** *Convair-San Diego, Division of General Dynamics Corp.*



and horizon are satisfactory. Another problem is: should the pilot believe his instruments at all times, or his own sensations? The 'window display' proposed by the author gives the pilot a simplified picture of the real world.

Cockpit

REVAMPED COCKPIT *of the future presents a simplified replica of the real world. "Window" display in center of panel can show actual view for visual flight, or modified view for instrument flight. Shadow symbol shows relation of aircraft to simplified terrain.*

AIRCRAFT COCKPITS today show an unfortunate resemblance to clock shops, surrounding the pilot with dials, pointers, and indicator lights. The pilot must monitor all these, remain aware of each displayed variable, and assimilate them into the aircraft's current and future flight pattern.

Thus it is understandable why considerable training and experience is required for the safe control of aircraft.

The need for simplification long has been apparent, and the obvious steps taken. Related displays (such as engine instruments) have been grouped and wherever possible combined (for example, airspeed and mach number).

But that was only a beginning. Data obtained in laboratory and simulator experiments made it possible to determine certain general rules of human behavior a pilot would exhibit when placed in a flight-control situation. These rules could be used to design integrated instruments for a more realistic representation of the environment. Pictorial quality of the new instruments permitted ease of interpretation, rapid training, and more dependable decision making.

The drive toward flyable aircraft

With the aid of new instrument designs and airborne computers, the pilot's task once again is manageable. Sensed data are processed and assimilated prior to their display, thus permitting the human operator to concentrate on the more important aspects of flight control. In the last few years the pilot has changed from an overly busy "tracker of variables" to a "monitoring decision maker."

The pilot receives a surprisingly great amount of information from his controls. Their position and "feel" provide knowledge of previously taken control actions and the aircraft's acceptance of new commands. As such, this feedback channel forms an essential part of the display picture.

For instance, conventional instruments displaying attitude (the angular relationship of an aircraft's longitudinal and lateral axes to the ground) are inside-out; that is, they show a moving horizon relative to the aircraft.

◀ Diagram at left shows an attitude display as seen in a right turn at a 45-degree bank angle. (The aircraft symbol is conventionally viewed from behind the tail.) This mode of attitude display assumes that the aircraft "up" is the only worthwhile reference axis.

Information: outside-in, or inside-out?

It also is possible to present the same information outside-in as shown on next page. Here the aircraft symbol becomes the moving member, and the earth's "up" is the only reference axis. Many experimental investigations have been undertaken to determine

which of these two modes is superior, but the controversy still remains unresolved.

In 1953, Dr. S. N. Roscoe, of Hughes Aircraft Co., designed a compatible instrument panel with respect to point-of-view. His search of the experimental evidence supported the "principle of the moving part;" that is, parts of the visual display that move always should represent the aircraft, or other objects that actually move, in relation to the fixed world.

Direction of displayed movement corresponds to direction of real-world motion. Based upon acceptance of this principle, he designed a complete panel, wherein *all* displays were read in the same manner.

Although it was a major step toward the compatible cockpit, certain features prevented acceptance of this instrumentation for production aircraft. Among other things the scale factors on both the altimeter and velocity displays were unsuitable, and pilots would have to change from the conventional inside-out attitude display to the outside-in mode.

The 'contact analog'

Pilots fly with relative ease under clear-weather conditions, using their "contact" with the real world. This asset plus the considerable background of experience which most pilots have in non-instrument flight led to the creation of a "contact-analog" display.

As conceived, the display would offer the pilot a highly pictorial representation of the ground so that he could fly by instruments under zero visibility using the same technique as in visual flight.

In order to approach this conception in a logical manner, it was necessary to determine precisely what information the pilot extracts from the real-world display as seen through his windshield. A large number of visual cues were listed, such as size, shape, linear perspective, terrain texture, and vertical location.

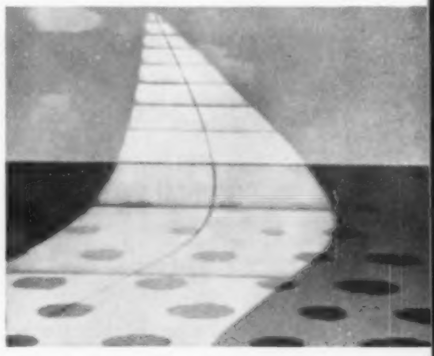
Each of these then was considered with respect to the aircraft's present and intended future status. Such a logical inquiry was of fundamental importance: *for the first time it identified the nature of specific information required to fly an airplane.*

Before long it became possible to mechanize the contact analog for simulator evaluation. A simple mechanical model of the terrain was viewed through a televisual link (see below). Motion of the slide in the projector and change of camera angle and height produce an image on the TV monitor which simulates position of the ground with respect to the plane.

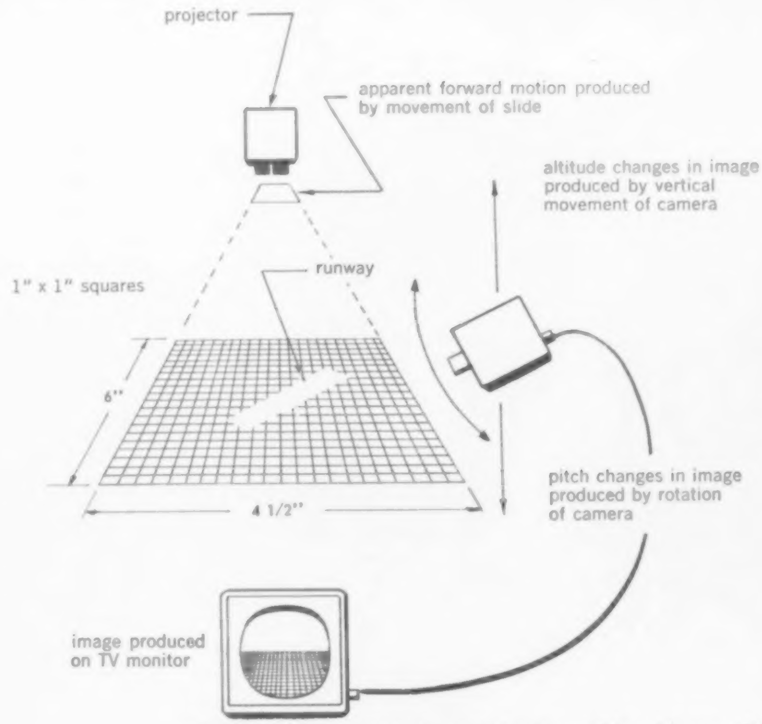
The first phase of the program met with success. As a result, the prime contractor for the Navy, Douglas Aircraft Co., let subcontracts to develop flight-test hardware. This included *a flat, transparent, cathode-ray tube* to display all "forward-view" information including attitude, altitude, velocity, etc. in an integrated manner. Such a transparent tube could permit the pilot to view either the artificially generated display, the real-world display, or both.

Highway in the sky

With the contact-analog principle as a premise, it became possible to present a "highway-in-the-sky" display. A computer generates a picture on a cathode-ray tube, providing the pilot with the display shown below. (The technique was designed by G. H. Balding, of Kaiser Industries Corp.)



The proposed cockpit has a pictorial forward-view, inside-out TV-type display, and a downward-view outside-in map display to provide navigation data, together with auxiliary instruments for quantitative data.



MECHANIZING THE CONTACT ANALOG *is possible with a model of the terrain viewed through a televisual link. Motion of the slide in the projector and change of camera position produce an image on the TV monitor to show relative positions of ground and plane.*

Because the proposed instrumentation was a radical departure from the state of the art, it became necessary to investigate individual features and displays both on the ground and in the air. The scope of the program was expanded to include helicopters, Army light aircraft, and even submarine cockpits. Bell Helicopter Corp. built a moving platform simulator with six degrees of freedom, enabling realistic study of instrumentation to allow safe zero-visibility hovering.

An active program is in effect to complete development of both the transparent flat-plate tube as well as the computer required to generate "highway-in-the-sky" signals. In the interim, development has progressed to the point where instruments with some of the basic features are being incorporated into production aircraft by Gruman Aircraft Engineering Corp.

Vertigo

The large percentage of accidents attributed to pilot error (41% in multi-engine jet and 45% in multi-engine non-jet) stimulated a fresh approach to cockpit integration at Convair-San Diego (see article *"Instrumenting" Air Safety*). It was intended to find some positive approach to each of the prime causes so far identified.

The first problem was vertigo, implicated as the major cause in 4% of major accidents and 14% of fatal accidents. Vertigo is defined as the loss of orientation. A psychological cause may occur when a disparity of orientation information is received by the human brain.

The pilot monitors his attitude in the air by reference to the attitude indicator, and at the same time receives attitude information through the vestibular canals of the ear and kinesthetic interoceptors distributed throughout the body. If these two information channels do not agree, then the pilot must decide which is correct.

Unbelievable instruments

Pilots are taught to believe their instruments as opposed to their own inner sensations—a difficult task for a man who has spent most of his life obeying body sensations and only a short time monitoring the attitude instruments.

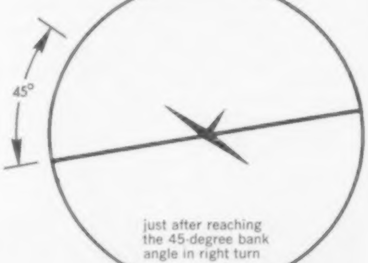
To make things even worse, the pilot often is faced with such a situation while under stress, and he fully realizes an improper decision might cost him his life. In fact, even the time he takes to make the decision may prove to be too great a delay. The instruction, "always believe your attitude instrument," is certainly a negative approach to the problem.

Inside-out and outside-in are not the only two possible modes for attitude display. However, these form the extremes of a continuum wherein *both* the aircraft symbol and the horizon move. Instead of being *aircraft-oriented* or *earth-oriented*, the display should be *pilot-oriented* so as to code the information in a most understandable manner.

Consider the kinesthetic sensing (the body's muscle sense) at, say, a 45-degree bank angle, As this maneuver is initiated, the pilot feels his aircraft tilt toward the right.

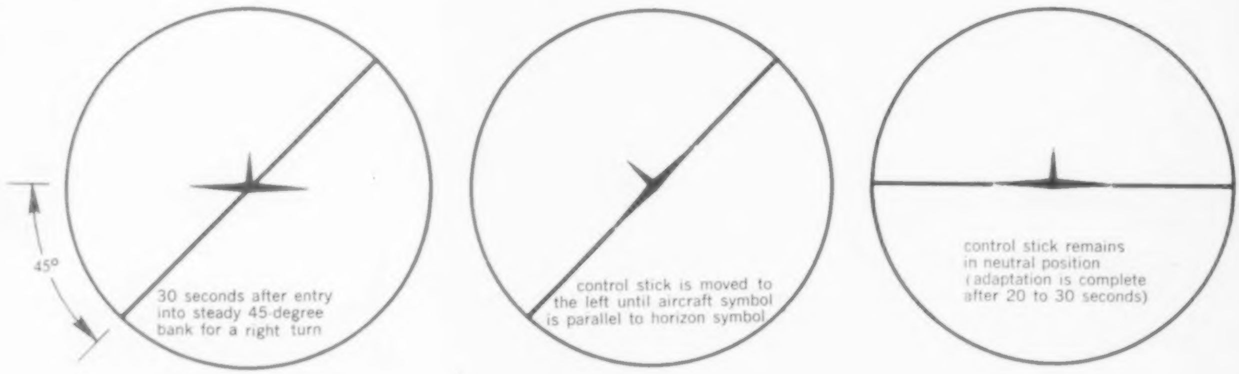
But his "up" reference is still the earth. Diagram above, a kinalog (for "kinesthetic and analog") display, shows the aircraft symbol moving in agreement with the human body's input.

By the time the 45-degree bank angle has been attained, adaptation of the body to the new position begins to take effect. The pilot's "up" will agree with the display as shown below.



***INTEGRATED INSTRUMENT PANEL** in the* F-106 Interceptor *is the "straight-line design" type. It has a single reference line across each group of related instruments for finding required data. The differences between the reference lines and command markers, set from the ground by radio, show the pilot the correction to be made. (Designed by Flight Controls Lab, Wright Field.)*

A jet pilot flew through a formation of six bombers, but saw on



Adaptation is reflected in slow counter-clockwise rotation of both the aircraft symbol and horizon. The true bank angle is the difference angle between the two moving members.

As adaptation approaches completion, the display appears as shown in diagram above, until a new control action is taken. While continuing in this steady-state turn maneuver, the pilot's "up" will agree with the aircraft's "up." Initially, the attitude display was almost completely outside-in, but as time passed it gradually proceeded toward inside-out. The position along this inside-out and outside-in display is dependent upon both time and the magnitude of the G force sensed by the pilot.

To recover to level flight, the pilot actuates his control stick until the aircraft symbol parallels the horizon. Level flight now has been achieved; however, the pilot's sense of "up" is as in diagram above. As time passes, both moving members rotate together (above, right).

If the example above had involved a pitch change, then the same kind of adaptation to the new pitch would have taken place. After the nose rises to the new pitch, both aircraft symbol and horizon gradually settle until finally the aircraft symbol once again is in neutral position.

A sudden dive would appear as a drop of the aircraft symbol to fall below the horizon line. As adaptation takes place, the two moving members gradually rise until the aircraft symbol reaches neutral position. A more complicated maneuver would show both members moving simultaneously.

As head of the reliability and analysis group at Convair-San Diego, Lawrence Fogel continually faces the practical problems of maintaining dependable flight, not the least of these being reliability of the human operator—known to be dependent upon cockpit design. Recent developments toward cockpit integration, including some of his own to-be-patented contributions, are described in this article. He now is preparing a book to appear later this year entitled "Applied Biotechnology" (Prentice-Hall). Fogel holds an MS degree in electrical engineering, and has completed course work for a doctorate. He has published some 32 technical papers, and plays a jazz clarinet, piano, and classical flute as "aircraftless" diversion.

Believable instruments

The important thing is that the instrument is *always telling the truth* about the present attitude. This information is read from the difference between the two moving parts. Both members "adapt" together without changing the difference reading, while they continue to maintain the pilot's knowledge of personal "up."

A second problem relating to anticipatory display is an outgrowth of increased speed and maneuverability of modern aircraft. Greater aircraft performance has compressed allowable reaction time to where logical decisions and even conditioned reflex actions no longer may be possible.

Even the simplest decisions require some finite time interval. For example, it is evident that the delay inherent in attitude decision-making may be sufficient to endanger life. To emphasize the immediacy of this problem consider a report from the *Journal of Aviation Medicine:*

hree of them. None of the six saw him, although he damaged one.

Case of the invisible bomber

"The pilot of a jet bomber was flying at 30,000 feet on a clear morning. He made a slow turn and was startled to see three other bombers approximately one mile away and on a collision course with him. Before he could react or alter the course of his aircraft he shot through the formation, missing the nose of the first aircraft, flying under the second, and over the third.

"As he went over the third bomber, one of his engines struck the upper part of this bomber's tail and knocked it off. The pilot who flew through the formation then returned to his home base, landed, and recounted his experience.

"Because no report had been received from the formation he had flown through, it was called and requested to land. When it landed, it was found that the formation consisted not of three aircraft—but of six.

"The aircraft whose tail had been hit was not significantly damaged—but what is amazing is that neither the pilot, the co-pilot, nor the observer in any of the six aircraft had seen the other bomber fly through the formation!"

One way to combat this problem is through the use of anticipatory displays—displays which present information relative to some future aspect of the observed parameters. In the simplest case, the display will indicate predicted values for each parameter. The pilot "flys" this projection of his own aircraft's present status. Even though the values he observes never may come to exist, his control should prove more precise.

Error is introduced by the prediction process, but this error, together with the pilot's error (which has been minimized by allowing sufficient time for decision making) will be far less than the error associated with the required almost-instantaneous, human response.

Human limitations

Another problem is the finite information channel capacity of the human operator. It is now recognized that there is an upper limit to the average information rate which any pilot can process successfully in accomplishing his flight-control task. Experimental evidence has shown that the error of human decision-making rapidly increases if the display complexity offers an information rate which exceeds this capacity.

Today, a large portion of the pilot's time is spent in directly controlling the vehicle. Technology provides him with more and more automatic equipment which he must monitor and program in order to direct the flight operation. Future pilot decisions may be fewer, but individually they will have much greater importance in accomplishing the mission. Less error will be tolerated. The instrument display must be designed to insure that its complexity will not exceed the human operator's channel capacity.

All consciously perceived information derived from any display takes up a portion of the available capacity for information processing. All data considered irrelevant to the required decisions should be eliminated from the display.

A simplified 'earth'

Confusion due to rough or obscure terrain might be eliminated best by furnishing a fictitious earth to the pilot—one which would appear as a map of the surrounding region with only predominant landmarks and characteristics identified. For example, the view of such a fictitious earth could be in three dimensions; mountains, color coded in altitude, could be replaced by polyhedrons defining the unsafe zone.

Such "modified pictorialism" would reduce the disturbing elements of nature's presentation. The example may not be a practical display design, but it points out that a modified pictorial display can be superior to the exact representation of the real world by reducing complexity.

Contact analog attempts to recreate basic features of the real world while *modified pictorial* attempts only to remove all unnecessary information from the real-world display.

'Window' display

The most informative view from an aircraft cockpit usually is forward and slightly downward. A forward view yields attitude information while a downward view offers earth-reference data. Here a single totally integrated display portrays roll, pitch, altitude, heading, position, and other flight parameters.

The proposed cockpit panel illustrated on page 62 contains a wide-angle "window" display configuration which helps solve the three accident-suggested problems. The particular situation presented shows the aircraft in an attitude of about 20 degrees right bank with 10 degrees pitch up (level flight would show the tail-viewed aircraft symbol superimposed on the horizon). The triangular aircraft-shadow symbol represents the position relative to terrain.

The terrain is almost undistorted under the shadow symbol and becomes increasingly foreshortened toward the horizon. The range to any point under the aircraft's imminent purview may be judged in relation to range rings which appear on the displayed terrain representation. Heading may be judged by reference to compass roses which appear at map distances to insure that at least one will be easily readable.

Terrain altitude may be read from the indicated color coding designating mountainous areas. For example, a red zone might require flight above 15,000 feet, while yellow might indicate a minimum acceptable altitude of 10,000 feet.

Cities are simplified in pattern, and almost all titles are omitted since it is presumed that the pilot became familiar with the terrain under his intended flight plan. Emergency runways are enlarged.

Judging velocity

Velocity may be judged by noting the speed with which the terrain appears to pass under the shadow symbol, in a manner similar to velocity judgment when looking out of the aircraft. Altitude may be judged both from the scale of terrain beneath the aircraft shadow symbol and the curvature of horizon. An increase in altitude makes the earth appear to shrink away, and a dive appears to bring the earth closer.

The display illustrated on page 62

is neither inside-out nor outside-in. A climbing right turn has just begun. As this attitude is maintained, pitch and bank angles remain displayed accurately in terms of fixed-difference distance and angle between the tail-viewed aircraft symbol and the horizon.

Both aircraft and horizon symbols then gradually shift toward placing the aircraft symbol in a central horizontal position in accordance with the pilot's adaptation rate under the G force he senses.

Cursory evaluation of the display has been accomplished through use of a jury-rig ground-based simulator. When 13 test pilots were familiarized with the simulator and accomplished sufficient control to form a first judgment, opinion was unanimously in favor of the general "window" display. A difference of opinion was noted with respect to the value of the kinalog mode of attitude display. This is understandable in view of the fact that it was necessary for the pilot to imagine the G force as he went into a maneuver.

The stick control

Because the control stick furnishes information to the pilot both visually and tactually, the best stick grip position is one that corresponds with the intended attitude of the aircraft. It might seem desirable at first to have the angular stick position simply correspond to attitude. However, this would present undue difficulties for all-attitude control.

A more feasible solution appears if the control stick position corresponds to the desired *change* of attitude. To increase pitch by, say, +30 degrees, the control stick is pulled back to that angle from the neutral position.

The aircraft immediately responds with increasing pitch. But as this occurs and error between present and intended pitch diminishes, an artificial force is placed upon the control stick, gradually returning it to its neutral position. This force is programed as some direct function of the error, such that a released stick will result in changing the intended attitude in a most efficient manner.

Similar action may be accomplished with respect to roll. Yaw control simply can be made correspondent to the angular rotation of control grip about its own vertical axis.

The entire cockpit is a display. It should be organized to minimize unnecessary distractions and present only the really significant information to the pilot with the fewest possible output devices. ■

AN ACCIDENT INVESTIGATION *calls for real detective work, plus lots of labor in gathering together every piece that can be found. Such painstaking effort can prevent many future accidents.*

'INSTRUMENTING' AIR

AVIATION is perhaps the prime example of man's struggle to stay ahead of the machine he created. From the beginning, more performance was designed and built into aircraft than the pilot could control under all conditions. Not that aircraft ever gave too much performance; rather, the pilot found himself lacking in means of monitoring and controlling that performance of which the machine was capable.

In the early days, the aviator stayed ahead of the aircraft by responding to basic physical stimuli. He flew literally by the seat of his pants—the pressure on his posterior. The machine was perfectly capable of performing at night or in obscure weather; the pilot was not. He couldn't rely on his eyes and ears and he had no mechanical substitute—no cockpit instrumentation, no navigation equipment, no efficient control devices.

So the pilot had to improvise in order to make up for these deficiencies. When the aircraft was climbing, or in a steep turn, he knew because there was added pressure on his posterior. If there was no pressure, he knew he was in some undesirable attitude, usually upside down. The pilot's skill was measured by how accurately and how quickly he could interpret these physical sensations and then make corrections to stay out of trouble. His job was to keep oriented, to go in the right direction at the right altitude with the aircraft in the right attitude. It was simple in theory but not in practice.

Compass to computer

Instrumentation was born of necessity. In 1934, we had some basic instruments—the magnetic compass, an airspeed indicator, an altimeter, and a somewhat questionable turn-and-bank indicator. It wasn't enough.

That was the year the Army Air Corps began to fly the air mail, a mission for which it had neither proper equipment nor proper facilities. The results are history. The accident rate was appalling. Pilots simply did not have the instruments and control devices they needed to control their aircraft under all kinds of operating conditions.

Not long afterward the needle-ball-airspeed artists were barnstorming the country, amazing the folks at county fairs. But aviation was more than a sport. Instrumentation continued to improve and by the late 1930s it had progressed to the point where all-weather flying was a practical reality. World War II brought us great experience in all-weather flying techniques. Cockpit instrumentation, control devices, and navigation aids became enormously more sophisticated.

Monitoring takeoff

Although progress has been literally fantastic, today as always, the performance of some aircraft is still ahead of the pilot's control and instrument equipment. In these cases, the safety factor undoubtedly could be improved by new or additional instrumentation.

Thirty-three per cent of all major aircraft accidents in the USAF last year occurred during the letdown and landing phases, and 20% during takeoff. Let's consider takeoffs first.

Military jets, particularly the *B-47* and the *B-52*, require some degree of takeoff monitoring. Thrust force at the beginning of takeoff is much lower for jet aircraft than for piston-driven aircraft. Therefore, it is diffi-

by **Maj. Gen. Joseph D. Caldara,** *deputy inspector general for safety, U. S. Air Force*

SAFETY

CROWDED AIRPORTS *mean crowded air space above. Mid-air collisions could be minimized with new instrumentation. Although the number of mid-air collisions involving Air Force planes is decreasing, the proportion grows.*

MODERN JETS AND THE OLD BIPLANE *are similar in some respects. Planes such as the F-104A (left) have performance limited by pilot's capabilities. In the BT-2A (right), instruments were sadly inadequate.*

cult for the aircrew to determine engine thrust performance and the aircraft acceleration rate accurately in the initial phase of takeoff. In addition, jet thrust decreases more in relation to rising ambient temperature than does propeller-type thrust.

Thrust sensitivity due to altitude also is greater with jet aircraft. Thus, a few degrees increase in outside air temperature and a relatively high airport means that a runway may be too short for safety.

Accidental runway overruns following aborted takeoffs are not unusual. Often such an accident results from a pilot's misjudgment: he believes takeoff acceleration is below normal so he aborts the attempt with insufficient stopping distance remaining.

Evidence indicates that in many of these cases takeoff actually was proceeding satisfactorily. On the other hand, there have been cases where the pilot felt takeoff was normal and didn't discover he had insufficient acceleration until it was too late for him to stop on the runway.

Right now, Air Force pilots have only a "line-speed" technique with which to check takeoff performance. By this system, a pilot uses performance charts of the aircraft to determine a predicted air-speed which should be attained by the time he reaches a given distance from the start of his takeoff roll.

This system forces the fighter pilot to divert his attention to find the appropriate runway distance marker at which to compare his speed during takeoff acceleration. Bomber pilots also have a problem because the copilot, who is assessing the takeoff roll, must communicate the information to the aircraft commander.

Indicating angle-of-attack

Thus, a versatile angle-of-attack indicator is one of the instruments most needed in the cockpit today. During takeoff, certain high-performance aircraft can be rotated longitudinally to an angle of attack greater than that angle which is optimum for lift-off. A marked increase in the length of the takeoff roll results. Where the runway length is already marginal for normal takeoff, this increase in takeoff roll can result in an accident.

After takeoff, the angle of attack continues to be critical. The influence of terrain also can cause the aircraft to be lifted off at an angle of attack greater than optimum; upon rising above the ground, the aircraft may settle back. An angle-of-attack indicator is necessary to give the pilot a direct reading of the correct angle of attack for each takeoff condition.

As the first deputy inspector for safety, Office of the Inspector General, USAF, Maj. Gen. Joseph Caldara heads up the Directorate of Flight and Missile Safety Research, Norton Air Force Base, Calif., and the Directorate of Nuclear Safety Research at Kirkland Air Force Base, N. M. Graduating from the University of Maryland in 1931, he became a second lieutenant in the infantry. A few months later he entered the Air Corps as a cadet. He has served in the South Pacific, Headquarters-Army Air Force, Alaskan Air Command, Joint Chiefs of Staff, and with the Strategic Air Command in California, Puerto Rico, Kansas, Japan, Guam. In 1959 he received the Benjamin Franklin Award, and the Monsanto Aviation Safety Award for making a "significant and lasting contribution to aircraft safety."

Such a device also could minimize accidents during landing. At present, the pilot uses his airspeed indicator as the primary instrument for attitude control during final approach for landing. To do this, he must compute a final approach airspeed for each gross-weight condition. In turn, this airspeed is controlled by changes in aircraft attitude, and the rate of sink by variations in engine thrust.

As the angle of attack is increased at approach speeds, small variations in engine output produce large variations in sink rate.

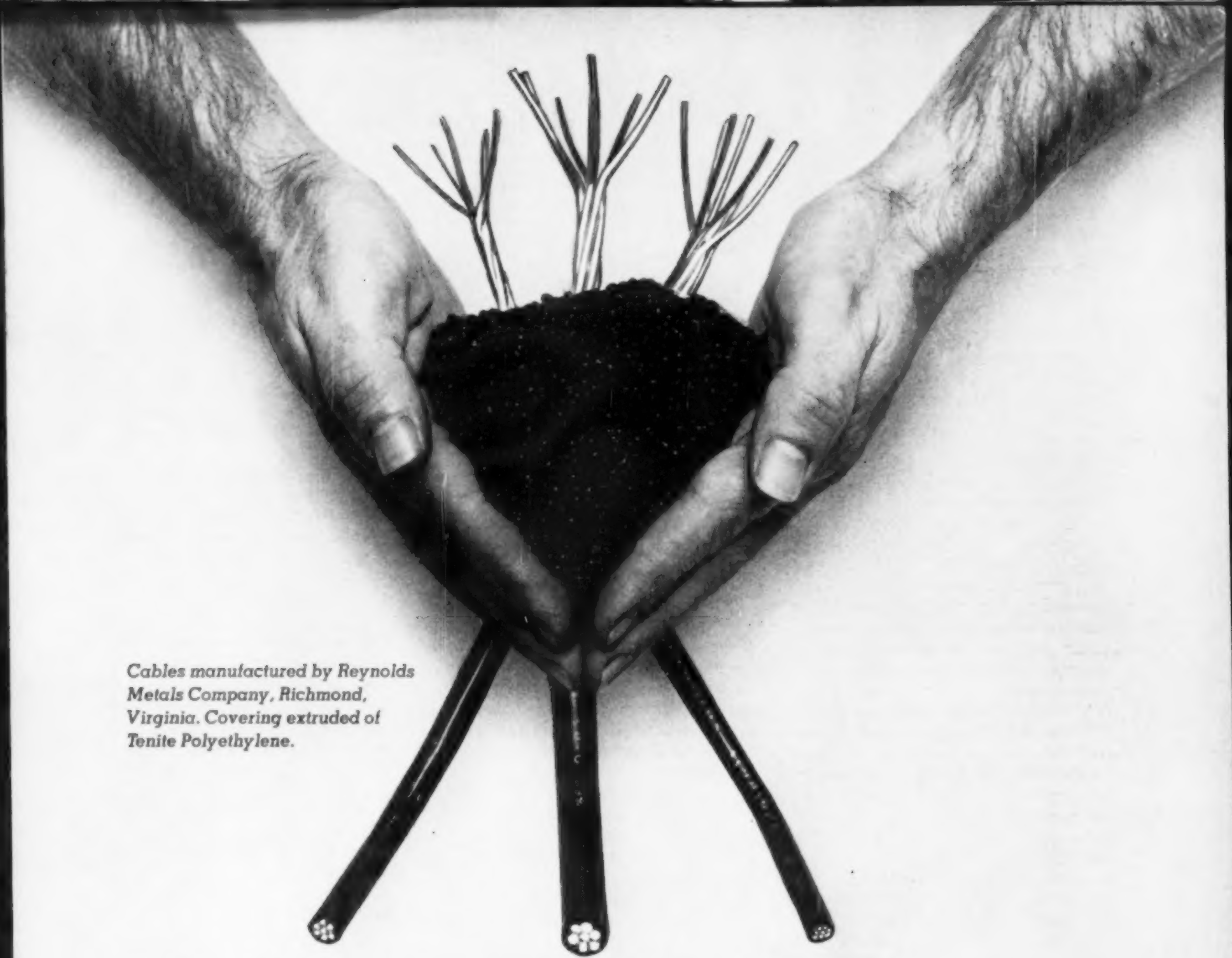
Problem compounded

This problem is compounded in high-performance aircraft by a combination of high-approach speeds, high-sink rates, and sometimes marginal visibility for the pilot because of the high angles of attack required on final approach. Night or poor weather means a further reduction in visibility.

Under existing conditions, the use of airspeed and rate-of-descent indicators to control the two variables, pitch and rate of sink, is dependent upon pilot judgment and technique. In many cases unfavorable combinations of these two variables result in a short or hard landing, or a long, fast landing.

Additionally, the slowest possible safe approach-speed schedule must be maintained to afford the pilot maximum time during the transition between breaking out from a low ceiling and reaching the runway.

The optimum aerodynamic angle of attack for any aircraft remains constant for any given set of conditions during level flight and in turns. An angle-of-attack indicator can provide the pilot with precise information regarding these variables and so enable him to maintain an aerodynamically correct angle of attack during the most critical phases of takeoff, approach, and landing.



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To obtain the highest possible performance from their secondary distribution and service line cables, Reynolds Metals Company chooses Tenite Polyethylene as a covering material.

Tenite Polyethylene is manufactured under as rigid a system of quality control as Reynolds' own aluminum conductors, and makes a tough, weatherproof, fast-stripping covering material which offers high dielectric strength and resistance to abrasion, heat, moisture, chemical attack and stress cracking. It remains flexible even at sub-zero temperatures and its light weight permits easy handling and wide spans. Users report that it gives long service life without festooning or splitting.

Tenite Polyethylene is easily extruded as jacketing or insulation for many diverse applications, from coaxials to control cables, from TV lead-ins to telephone wires. For a material with outstanding electrical, physical and chemical properties, specify Tenite Polyethylene. For further information, write Eastman Chemical Products, Inc., subsidiary of Eastman Kodak Company, Kingsport, Tennessee.

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Fire-warning devices

Another important safety instrument is the fire detector. Aircraft fire-warning devices have been in operation for several years, yet the Air Force still lists them as critical for further development. Why?

Because the detection and control of over-temperature conditions in modern military aircraft have not kept pace with development of aircraft power plants. Today's military aircraft must be operated at their maximum tactical capability. When power plants are strained for the ultimate thrust they can deliver, there is sometimes a progression of events that leads to overheating, fire, explosion, or all three.

What we need today is a fire-warning or detection unit with ultimate simplicity and reliability, giving maximum safety with minimum equipment. Our jet aircraft fleet has had fire-warning systems for several years, but lack of reliability in the system has been a frustrating, costly experience.

The problem has centered primarily around false fire-warning indications—just as bright to the pilot as the real thing. There are several instances on record where high-performance fighter aircraft have been abandoned because of false fire indications.

In other instances involving multi-jet aircraft, accidents have resulted from power reductions and fuel shut-off procedures initiated as a result of false warnings. A particularly hazardous aspect of fire in a compact, fuel-laden aircraft is that an explosion may follow. In this respect, numerous crews have stayed with their aircraft and spent many anxious moments analyzing fire warnings that turned out to be false.

As a result of hundreds of false fire-warning indications in the *B-47* fleet of the Strategic Air Command, a decision was made to disconnect the system. It was simply a question of which was the greater risk, an unreliable fire-warning system or no system at all.

Those mystery crashes

Accidents of a mysterious nature have created considerable public alarm in recent months. Since military as well as commercial planes occasionally suffer accidents due to "undetermined causes," what kind of device is needed to take the mystery out of sudden crashes?

Of 675 major aircraft accidents occurring throughout the USAF last year, the primary causes of about 14% still are undetermined. Once an aircraft is in service, no comprehensive record of its performance can be made. Failures usually are displayed on indicator lights or similar devices, then noted from the pilot's memory after landing.

An automatic flight recorder which would reconstruct the flight plan and instrument indications is a must for accident investigation. The recorder must be a standardized unit and be capable of withstanding intense deceleration forces and temperatures.

Accidents occur when the aircraft does not respond to the pilot's wishes, or when he incorrectly interprets information, through instrument error or human misunderstanding or misjudgment. A record of the conditions of flight would aid in the investigation of a failure or crash, and remedial measures could be instituted immediately.

Coupled with such a recorder is the need for a device to measure the intensities of vertical acceleration, better known as "gust loading." When excessive gust loadings are encountered, an aircraft's speed must be decreased to maintain a safe structural load-speed ratio. After severe gust loading, an inspection of the aircraft for structural failure is required.

A flight recorder showing the exact amount of gust load encountered during flight would indicate the range and degree of inspection required after landing. Gust loads between two and two-and-a-half Gs are not severe, and visual inspection of the outside structure may suffice. Loads between two-and-a-half and three-and-a-half Gs may call for internal inspection of the most highly stressed points, but not entail removing the aircraft from service. Stress of four Gs and above probably would demand a complete structural inspection.

A record of the gust loading to which an aircraft has been subjected throughout its service life also would provide a basis for fatigue studies.

Mid-air collisions

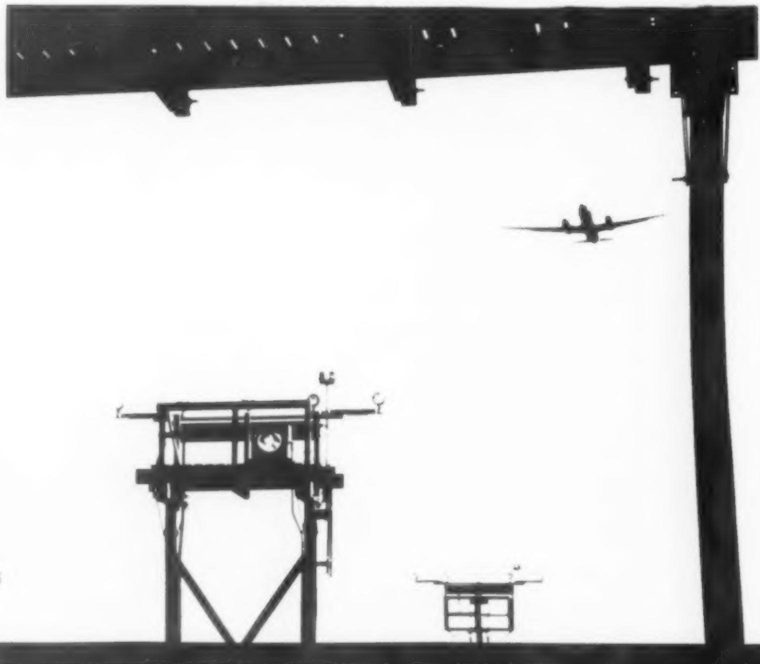
Possibilities of mid-air collisions also could be minimized with new instrumentation. The Air Force had fewer mid-air crashes last year than during any previous year, and as of this writing has not been involved in a collision with a civil transport since May, 1958. Yet, since 1947, with only minor reversals, the proportion of mid-air collisions to all major aircraft accidents in the Air Force has increased.

It is clear that we have reached a point where the human operator cannot consistently avoid mid-air collisions without mechanical aids. We still must rely heavily on see-and-be-seen methods in terminal areas and traffic patterns to supplement radar monitoring and traffic control. But the days of see-and-be-seen flying at high-cruising altitudes and airspeeds have all but ended.

Any effective anti-collision measure must provide the pilot with information outside his own visual limitations. And such a device must be developed in terms of realistic measures of the time it takes a pilot and machine to react in order to avoid a possible collision.

It may involve a cockpit presenta-

VISUAL LANDINGS *require a high degree of skill in interpreting several instrument values. Instrument landings place even more demands on the pilot's judgement.*



Instruments for greater safety must be considered in the original design, not after the plane is already built.

tion to the pilot or connections with an autopilot, which would automatically provide course variations without human intervention. Any device involving cockpit presentation must be considered carefully to make sure the hazard created by additional cockpit scanning time is not greater than that eliminated by the device itself.

It is possible that positive control from the ground may be the answer to this particular problem. Such control, however, must govern all users of the air.

In 1957, an Air Force-industry conference considered anti-collision devices at great length. It was the consensus that a device was needed both to warn the pilot of the threat and to indicate a safe course of action. Considerable progress has been made since then toward development of such a device, but a satisfactory piece of hardware is not yet available.

More progress has been made in improving cockpit instrumentation, a term covering all problems ranging from information deficiencies of instruments to their arrangement in the cockpit.

Putting instruments together

As aircraft performance increases, the pilot must perform more and more functions in flight. To assist him, several instruments have been combined into one, made smaller, or rearranged. For instance, Mach and airspeed information, originally displayed on separate instruments now are combined.

The importance of locating equipment with great care cannot be overestimated. One example: under instrument weather conditions, accidents have occurred when a pilot was required to change radio channels or identification, at a time when he should have been giving maximum consideration to his flight instruments.

In order to do this in some aircraft, the pilot must change control of the aircraft from his right hand to his left, then lean forward and downward, and turn his head. The reflex action of the body is such that it is very difficult to maintain the aircraft in proper attitude with the body in this position.

Additionally, the quick straightening of the body is conducive to a Coriolis-type disorientation. The combination of partial disorientation, an unexpected instrument display, and time at a minimum is certainly conducive to loss of control. This type of diversion now is being alleviated by relocation of the communications equipment, but there are many other problems to be investigated.

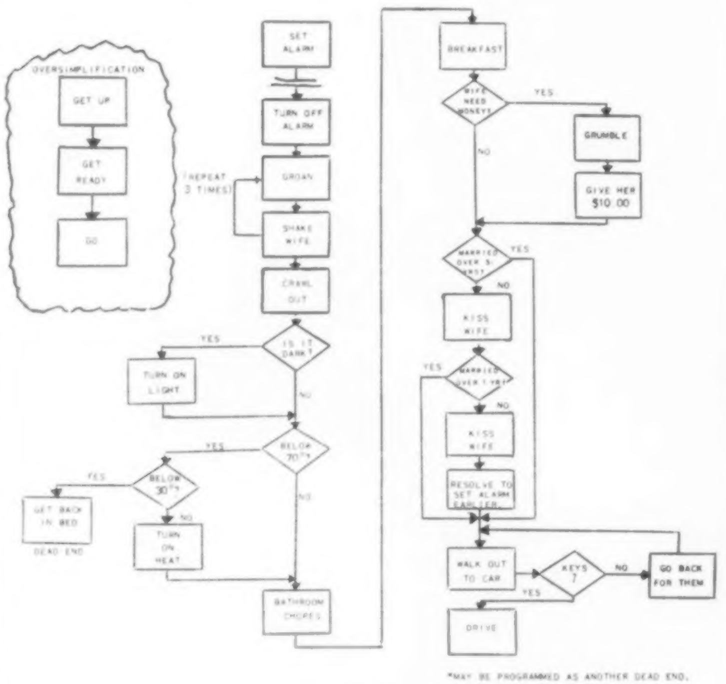
The cost of retrofit

Correcting all these situations would require extensive retrofit programs for old aircraft, and the cost would be prohibitive. We could have afforded some of the now-prohibitive retrofit devices (at perhaps one-tenth the retrofit cost) had they been available during initial aircraft design.

Had instrumentation and other monitoring and control devices been in equal state of advancement with the performance capability of our present-day aircraft, the man-machine relationship would be on a more even kilter. This is "Monday-morning quarterbacking," to be sure, but it also demonstrates how we can price ourselves out of business, both within the Air Force and without.

Safety must become integral with original design—not retroactive. Mach 3 aircraft are now on the drawing boards. It now is conceivable to develop military and commercial aircraft capable of operating at hypersonic speeds and at altitudes heretofore unknown. It also is conceivable to match aircraft performance in the initial design with safety and control devices for a better man-machine relationship. ■

getting to work in the morning



Building a computer program requires first laying out a logical diagram of all steps in the computation, including alternative courses of action and application of tests which affect the next computer operation. Programing time and skill should be considered in analyzing computer costs.

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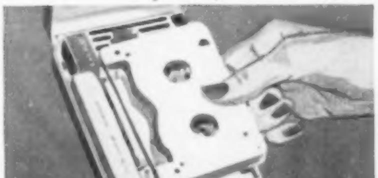

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During his association with Melpar, Joseph Campanella has performed studies and development on fire-control systems, data-processing computers, spectrum-analysis equipment, information theory, and communications systems. He is now technical consultant. His prior experience was at the Naval Research Laboratory. Campanella received a BEE degree (magna cum laude) from Catholic University of America, and an MS from the University of Maryland. He belongs to the IRE, American Ordnance Assn., and the Acoustical Society.

by **S.J. Campanella,** *Melpar Inc.,*

Paul Cohen, *Sperry*

analog

VERSUS

IN A DIGITAL COMPUTER, all calculations are carried out in terms of discrete quantities represented by numbers. The basic principles of the digital computer date back to Babbage who, in 1888, devised a "calculating engine." The conventional desk calculator is a digital machine which, when manually instructed by a human operator, can be made to perform virtually any calculation.

Instructing the computer

In the automatic computer, instructions for the selection of an operation and the disposition of encoded numerical data are stored and used to control the machine. High speed of computation results from improved efficiency.

Although the machine can perform computations at high speed, preparation of the instruction program is a skilled job requiring detailed examination of the problem's logic and arithmetic.

A typical digital computer contains input devices for acceptance of data and instructions, memory units in which numbers and instructions can be retained for later use, a control unit to interpret the instructions and arrange the correct operation, and output devices for presenting results.

A digital computer is a composite of simple units, each performing a logical step fundamental to the mathematical computation. It can perform elementary arithmetic operations such as addition, subtraction, multiplication, division, and a variety of logical operations such as sign sensing. The machine can be programed to perform selected sequences of elementary operations, such as differentiation, integration, and solutions of algebraic equations.

Specialized analog computers

Analog machines are of several types, but their behavior can be made to obey mathematical relations identical with or closely related to those of the system being studied. Such machines, in effect, may be models of the system.

Unlike the digital computer, in which computer components enter equally in all functions performed, the analog computer is comprised of a system of components each performing one of the mathematical operations required in a solution.

For example, each multiplication employs a separate servo-driven potentiometer or incremental inductor; each integration employs a d-c feedback amplifier.

By properly interconnecting such components in accordance with mathematical relations involved in the solution, an analog computer is produced. It is evident that a considerable amount of function duplication is present in analog computers.

A typical analog-computer application is a flight simulator used for pilot training. Such computers solve the aerodynamic equations for motion of a particular type of aircraft. Inputs to the computer are produced both by the trainee pilot with his conventional control mechanisms and by the instructor who may insert malfunctions or changes in wind speed, drag coefficient, or engine thrust.

Analog-digital systems

The future will bring an expanding use of digital-computer techniques in control applications, but such devices will not be entirely digital. This follows because in almost all physical processes the phenomena observed and the required control are analog quantities.

Hence, computers employing digital computational procedures must possess input and output devices which either convert from analog to digital, or digital to analog.

The introduction of such conversion devices limits the general-purpose nature of digital-computer elements of the machine, and the overall computer becomes a special-purpose machine. To simplify the program and reduce cost, sub-

Since he joined Sperry in 1946, Paul Cohen has worked on an aircraft torpedo project, a long-range missile design project, fire-control problems, and computers for submarine ordnance. He is now engineering section head for anti-submarine warfare. Cohen also taught at MIT and has worked in the research division of United Shoe Machinery Corp. He received a BS degree from MIT and an MS in applied mathematics from Adelphi. Cohen holds three patents, and has published several papers.

Frank Dailey has attended Niagara University, the US Naval Academy, from which he received a BS in electrical engineering, and the University of California, from which he received an MS in applied physics. He has been with the Naval Ordnance Lab as senior military advisor, the U.S. Navy as administrative officer and electronics officer, and is now manager of the applied science laboratory of Stromberg-Carlson – San Diego. Dailey is active in the Naval Reserve, and is a member of the US Naval Institute and the American Ordnance Association.

e Co., Division of Sperry Rand Corp. *and* **Franklyn E. Dailey Jr.,** *Stromberg-Carlson-San Diego*

COMPUTERS

digital

routines are built into the machine. The machine thereby is adapted to a certain class of solutions which it solves best.

Various factors influence the choice of a computer—accuracy, flexibility, speed of computation, reliability, maintenance, and manufacturing requirements.

The cost of accuracy

Accuracy limitations are radically different for analog and digital computers. In general, analog computers can be constructed economically for accuracies up to 0.1%. Further increased accuracy is possible, but only at sharply rising cost, and it is unlikely that accuracies can exceed 0.001%.

Cost of analog computers for applications requiring accuracies of less than 2% is usually less than that for a corresponding digital device. For accuracy requirements better than 0.1% the digital computer becomes increasingly attractive economically. The accuracy of the digital computer is limited only by that of the input data, and the speed of computating imposed by some problems.

What about flexibility?

In general, the analog computer tends to be a special-purpose device by its very nature. Each unit usually performs a single operation dictated by the step it executes in the solution, and is not employed for any other purpose. This makes the analog computer most desirable when a study is performed repetitively.

The analog computer is also most easily adaptable to problems in which both the input data and the answer occur in analog form, such as problems involving simulation of physical systems in real time.

Digital computers, on the other hand, were conceived originally as general-purpose devices capable of solving various problems. This is a consequence of the fact that the digital machine is an aggregate of units capable of performing the basic mathematical operations common to all computations.

To make a digital computer perform a specific computation, it must be instructed in much the same manner as a desk calculator—the instructions being given by a program stored in its memory. Flexibility of the digital computer lies in the ability to change its program. In the analog computer, a program is difficult to change.

Digital computers tend to become special-purpose machines when they are designed specifically to excel in a certain class of computations. This results because of limitations imposed both by the input devices attached to the computer and by computing routines semi-permanently wired into the machine. Such machines are entirely practical even though they have limited flexibility.

Both analog and digital computers can perform computations on a real-time basis. Because of their general-purpose nature, digital machines have been used principally for complex problems requiring extremely accurate answers. Developments in digital computers resulting in considerably reduced size and weight now have made digital computers attractive for the solution of problems requiring high-speed solution.

For example, a digital computer performs all the functions necessary to navigate a supersonic aircraft to an attack position, release its weapons, and return the aircraft to a home base. Analog computers are not considered satisfactory for this job either from the viewpoint of speed of solution or flexibility in handling the variety of computations involved.

Advances in digital-computer design, especially the use of solid-state components, have enhanced reliability of digital computers. They now challenge analog computers in this respect. Solid-state components have not contributed equally to analog-computer design because of

drift and non-linearity of electrical parameters.

Modular construction

Maintenance is primarily a matter of good design both in analog and digital computers. Wide component tolerances designed into the circuitry permit replacement without precision-matching of replacement components. Use of modular construction permits exchange of the module with a new unit, repair being postponed until a more convenient time.

It is desirable to design the modular system with a minimum of different modules, which gives an advantage to the digital computer. A large machine can be assembled from a small variety of basic components, whereas an analog computer has as many different modules as there are arithmetical or logical functions to perform.

Another important maintenance factor is that self-testing features can be built into either type of computer, but are more easily built into the digital machine. Self-testing can simplify maintenance by providing not only a means of discovering a malfunction, but of localizing and correcting it.

Economic outlook

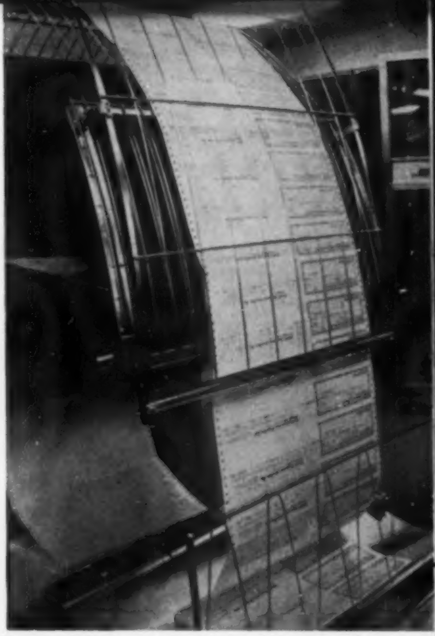
The first digital computers were extremely large devices employing brute-force methods of data handling and storage, and possessing poor reliability.

Advances in speed, reliable solid-state circuits, increased density of storage with reduced access time, and improved programing methods all have aided greatly in reducing size, weight, and power requirements for the digital computer, and the trend is continuing.

Miniaturization also has improved the size and weight of analog computers but results are not nearly so impressive as for digital computers. Printed-circuit techniques, microminiaturization, use of standard circuit modules, and automatic assembly of these modules will make digital computers economically competitive with analog computers when both are capable of doing the job.

Probably the real motivations for going to digital computers are requirements for greater accuracy and versatility and the need to solve complex problems. The pressure of such factors, coupled with the continually improving technological outlook for the digital computer, eventually will result in either partial or complete implementation of many operational control systems by digital techniques. ■

LINKING COMPUTERS *by microwave increases flexibility and problem-solving capabilities. North American Aviation prints pay checks (right) from radio-transmitted data. Cost control information is processed further after reception (below).*



Analog or digital computer?—current trends

■ Analog computers are losing out to their digital companions for most applications. Even where analog computers once reigned without dispute—as in data logging and control systems—digital devices are taking their place.

The introduction of computers sometimes has created tremendous quantities of information such as records and test data, which are of potential value for future planning. The volume of such information has proven so formidable that computers were needed to digest it in reasonable time and with reasonable labor.

Data in digital form are much more readily interpreted than analog data, and are much more readily stored or transmitted from one place to another.

Consider the new computers that have been developed and marketed in recent years; almost all of them have been digital types.

Some devices called "analog computers" also could have been called "control systems." While digital-computer service centers are being opened and expanded, analog-computer installations are idle much of the time.

However, analog building blocks still have a very important function—for simulation of physical systems. They permit great flexibility in studying different system designs.

As the design progresses, computer building blocks can be replaced with actual components of the system under study to approach more closely the performance of the final system. ■

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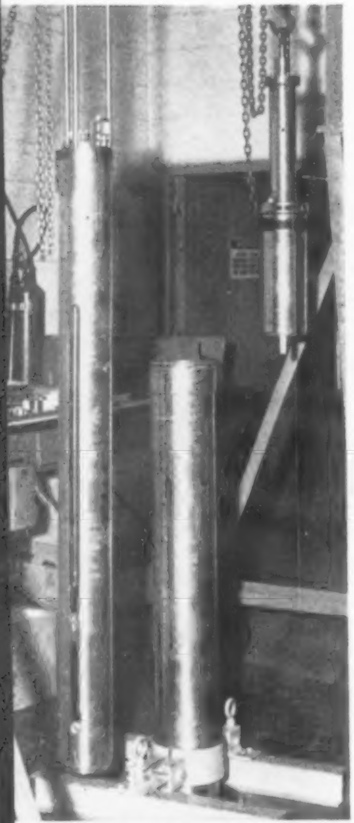


Neutron flux control is the key problem in safely operating a nuclear reactor. Instruments for measuring the reaction rate must have a tremendous range—a billion to one. Safer operation of the reactor results when reliable readings of neutron flux are obtained over the entire power range.

CONTROLLING THI

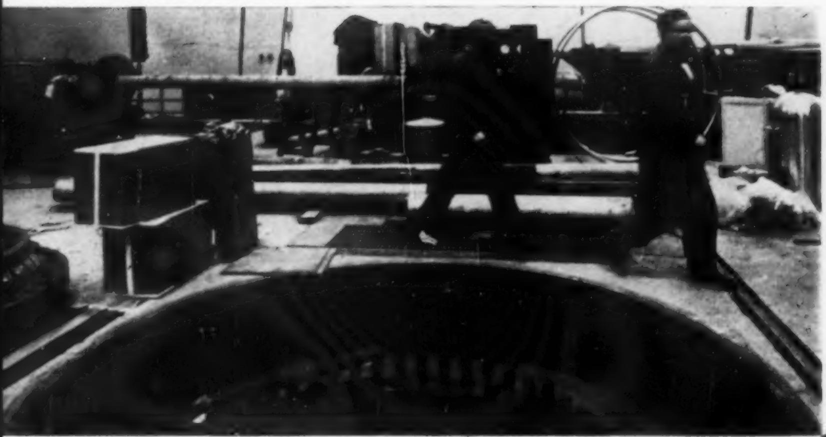
by **Joseph M. Harrer,**

associate director,

reactor engineering division

Argonne National Laboratory

CONTROL ROD *drive mechanism (upper left), suspended inside steel frame, is undergoing mechanical tests. Mechanisms such as these determine rate of the nuclear reaction. Fuel element (lower left) is being removed from Argonne National Laboratory's CP-5 research reactor during a refueling operation. This reactor is used by Argonne staff and other organizations for diverse experiments, such as testing effects of radiation on materials, and fundamental studies.*



EXPERIMENTAL
boiling water reactor (left) has been opened for refueling. It is providing data valuable in designing future reactors for economical production of electric power. Analog computer (below) at Argonne is an important tool for reactor analysis and design.

NUCLEAR REACTION

SAFE OPERATION of a nuclear reactor requires reliable and accurate instrumentation to reveal what's happening inside.

The most important parameter to be controlled is neutron flux, the product of neutron density and velocity (measured in neutrons passing across a square centimeter cross-section in a second).

The fission rate in the reactor depends upon the number of uranium-235 atoms present in a unit volume of the fuel and the number of neutrons capable of fissioning these atoms. When the fission rate is high enough, a self-sustaining nuclear chain reaction is achieved.

The main difference between measurement of neutron flux in a nuclear reactor and measurement of temperature or pressure in other industrial processes is the range which the neutron-measuring instruments must cover. Consider a chemical process operating at 1,500 pounds per square inch pressure. When starting the process, the pressure is one atmosphere, or about 15 psi. Here, the range of pressures to be measured is 100 to one.

Measurement range: a billion to one!

In a nuclear reactor, the initial value depends upon the source of neutrons used for reactor startup, typically about 10 neutrons per square centimeter per second. At the operating point, the neutron flux might be 10 billion neutrons per square centimeter per second. Here, the required instrumentation range is one billion to one, a reasonable value for most practicable reactors.

Power developed by a nuclear reactor depends upon the total number of fissions per second. For example, a small reactor with a neutron flux of 10 billion would produce in the order of 1,000 watts of heat.

Selecting the neutron source for start-up is the first engineering consideration in the design of instrumentation. For a reactor to produce several million watts power, the engineer would build a relatively strong source to keep the range of instrumentation within the billion-to-one range. Safer operation of the nuclear reactor results when reliable readings of neutron flux are obtained continuously from the initial value all the way up to the operating power.

Visualize the uncertainty facing the operator trying to run a reactor without knowing the *rate of change* of the fission process. The variable controlled by the operator (or by the control system) is the reactor's reactivity, a measure of the rate at

Joseph Harrer is project manager of Argonne's experimental boiling water reactor. His work at the lab since 1948 has involved reactor instrumentation and control. Previously, Harrer was with Clinton Labs (now Oak Ridge), Tennessee Eastman Corp., and Bausch and Lomb Co. Harrer received a BS in EE from Rensselaer Polytechnic Institute, and an MS from Illinois Institute of Technology. He has taught at IIT.

New instruments and new materials are needed if nuclear reactors are to be used efficiently for production of power.

which the neutron flux is either rising or falling.

For example, at zero reactivity, the flux is constant. If the fission process is self-sustaining, the condition is called "reactor critical."

Controlling reactivity

For all reactors, mechanical devices are provided to control reactivity. These controls are installed in the core to change the rate of neutron production. One common method of control is to move U-235 fuel in control rods into or out of the core to change the "critical" amount of uranium present.

Another, less efficient, method is to use control rods containing boron, cadmium, or hafnium to absorb neutrons in competition with the uranium and therefore cause neutrons to be lost to the chain reaction.

The operator's job is to control neutron flux by moving the control rods. To increase the flux, he moves the controls to gain positive reactivity. After the flux rises to the desired value, he sets the rods for zero reactivity and levels the flux.

What's a safe period?

A measure of the reactivity is the reactor's period. This indicates the instantaneous rate of rise of neutron flux compared to existing flux. The period is the same when the rate of rise is one neutron per second with 10 neutrons present, or when the rate of rise is 10 neutrons per second with 100 neutrons present.

Normal practice limits the period to a safe value, typically about 10 seconds as in the examples above. Shorter periods could cause rapid heating and thermal expansion of uranium elements, damaging the core.

A simple electrical computer is used to measure flux period. This computer is useful to the operator, but it also actuates automatic protective circuits to keep the operator from raising flux too rapidly.

Neutron flux is measured using ionization chambers. These devices contain a gas and a pair of electrodes to which a voltage is applied. The gas or an electrode contains either boron or uranium.

Neutrons entering the chamber are absorbed by these materials. Ionizing radiation is produced almost instantly, causing the gas to conduct current. A sensitive meter in the electrode circuit indicates the rate at which neutrons strike the chamber, thus measuring the neutron flux.

The chambers usually are positioned as close to the reactor as possible to obtain high sensitivity. Some are placed inside the reactor core, but this is not common practice because the chamber absorbs neutrons and reduces reaction efficiency.

Neutrons leak out

In some reactors, intense heat and radiation within the core pose a design problem. A number of neutrons always leak out of the reactor core volume and are lost to the fission process.

The number of leaking neutrons is roughly proportional to the number present or taking part in the fission process. Thus, placing the neutron-sensitive chamber in these leakage neutrons is an effective way of measuring flux for control purposes.

Before startup, the flux is low. If the reactor design is efficient, chances are that only one neutron or less will reach the sensing chamber every second, and the electrical current is in pulse form. "Counting rate circuits," are used to measure the pulse rate.

During startup, the pulse rate increases, eventually becoming a continuous current. Less-sensitive chambers then come into operation and give an electrical current proportional to flux.

Limitation of material

In a nuclear power reactor, the uranium fuel must be cooled. These reactors operate at temperatures over 400 F. The nuclear process is not adversely affected by high temperatures—and there lies the challenge to reactor engineers. When structural materials are found to support the uranium, core temperatures can be raised to values not now possible with oil or gas.

A number of temperature, flow, and pressure instruments are used in most reactors. One important function of all instruments is to prevent damage to the reactor core. Thermocouples, ordinarily used to measure temperature, present minor problems because neutrons affect their calibration.

Nuclear reactor safety is a mandatory goal of the engineer. A power-reactor core contains huge quantities of radioactive material in the form of fuel rods or assemblies. The danger lies in melting or rupturing the core materials and releasing these radioactive materials to the atmosphere. Preventing damage to the core is the first line of defense against a serious radiation accident. In this function, all of the instruments associated with a nuclear reactor are important.

When control rods shut down the reactor by quickly producing a negative reactivity, the action frequently is called "scram"—stemming from the early idea that if the reactor were in danger of being destroyed, the personnel should "scram."

The control engineer designs an electrical system to activate the shutdown system in a few thousandths of a second. He uses sensing instruments to detect abnormal values of neutron flux, neutron flux period, temperature of coolant or fuel assemblies, and flow of coolant.

Inside the core

A decade ago, the instrumentation and control of a nuclear reactor were arts to be developed. Today, much of the needed equipment is commercially available. Similarities of instrument systems for different reactors has led to a great deal of standardization.

Each reactor type presents unique problems, but systems can be designed using commercial components. Very little development is required for present-day reactors. But in this rapidly changing field, new reactor concepts surely will demand new instruments and control systems.

Measurements are difficult to make inside high-power reactor cores. The problem is being explored vigorously and must be solved quickly if reactors are to be used efficiently for the production of power.

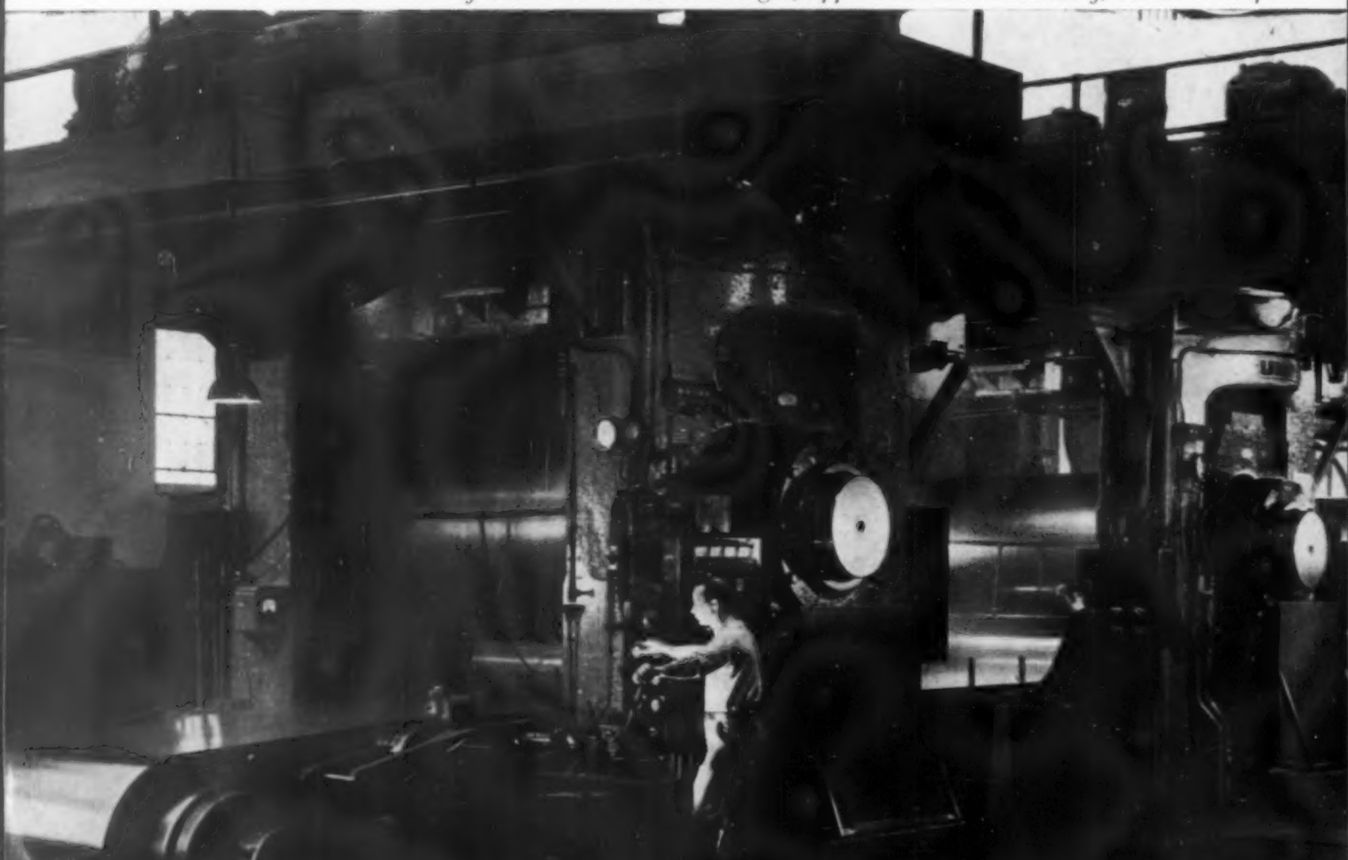
We must find out exactly how a nuclear reactor performs and how to operate closer to design limits. There will be pressure to use materials in reactors at stresses beyond those presently accepted in normal design. In this respect, development of nuclear reactor instruments hardly has begun. ■

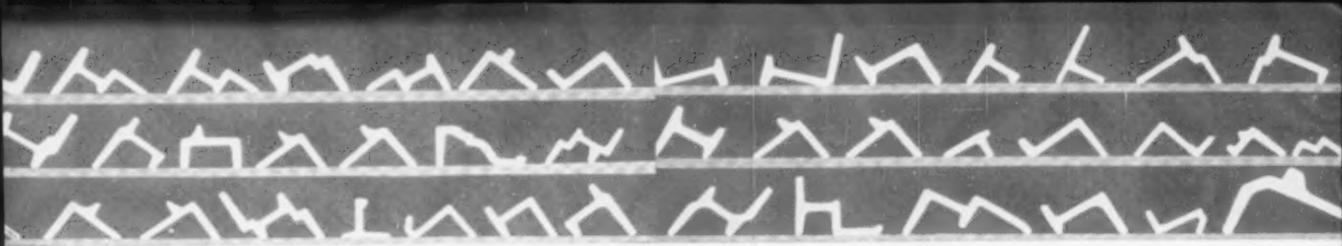
ROLLED STEEL SHAPES *of almost endless variety and for many uses are formed in a rolling mill.*

Control of rolled steel thickness presents instrumentation problems. A unique solution is to use the rolling mill itself as a thickness-measuring instrument and as part of the control system.

The Rolling Mill as

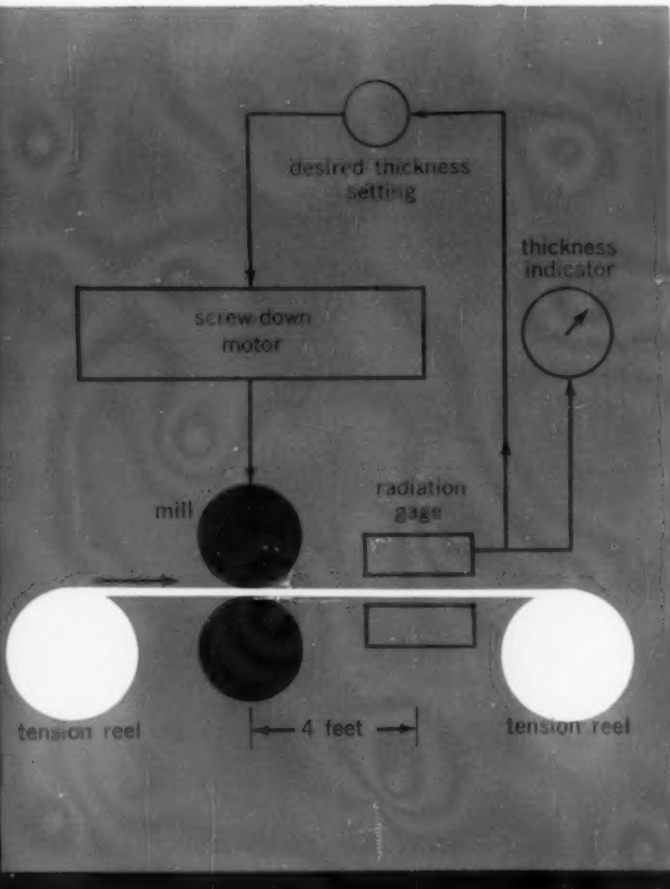
by **T. K. Cauley,** *technologist, Applied Research Laboratory, U.S. Steel Corp.*





Thomas Cauley, an MIT electrical engineering graduate, is a technologist in the electromechanical engineering division of U.S. Steel's applied research laboratory in Monroeville, Pa. Formerly he worked with microwave relay links at Federal Telephone and Radio Corp., and prior to that designed carrier communications equipment for Femco Inc. He currently is working on a speed-regulated twin drive for structural mills to control product shape.

an Instrument



ROLLING MILL *(at far left) is being used to make strip steel. Diagram at left shows a thickness control system using a radiation gage. Principal disadvantage is that response time is slow.*

IMPROVEMENTS in the quality and uniformity of rolled steel during recent years are due in large part to instrumentation advances. Better thickness transducers, such as contacting micrometers and radiation gages, along with developments in pyrometry and metallurgical analysis, have contributed. Improved steels are processed readily in presses and forming machines, and are more predictable in strength, weight, and performance characteristics. But customers still demand better uniformity.

Techniques from other fields

The need for improvements in measurement, inspection, and control of rolling processes is being met in part using techniques well established in other fields. Instead of relying on rolling-mill operators to monitor thickness gages and make necessary corrections in screw settings or rolling tensions, an electromechanical system can perform these functions automatically.

While a feedback control system (see articles on *Adaptive Control*) inherently corrects any error that exists between reference input and controlled variable, the corrective action under certain conditions causes instabilities. This is especially true if the control element has a large compensating effect on the controlled system and if significant time delays are present in response of the control element or the feedback element. Needless to say, an unstable control system is worse than no control system at all.

The requirement of control-system stability — including the system's ability to recover following a disturbance — is not compatible with accuracy of control. Time delays in the actuating signal may allow a fast-acting control element to overshoot its required setting and cause an error in the reverse direction. The result is an unstable system.

Time delays in a feedback control system set the accuracy limit of the system. To improve accuracy and maintain stability, time delays must be reduced to a minimum.

The diagram at left shows a typical reversing mill with a radiation-thickness gage arranged for contin-

Needless to say, an unstable control system is worse than no contr

uous control. In such systems the gage is located typically about four feet from the roll. Thus, any thickness error in the strip must be transported four feet before being detected by the gage. This transport lag is a possible source of instability if the response time of the control system is somewhat less than the time required for the steel to move four feet.

When a correction is necessary in the screw setting of the mill, contactors are closed to actuate the screw motors. The resulting time delay is dependent on the speed of the screw-down system and the stiffness of mill rolls and housing.

If better mill performance is to be achieved, it is necessary to compensate for the transport lag between monitor gage and rolls. One either may provide some means for anticipation, or minimize the delay by moving the monitor gage closer to the rolls. Both approaches have practical limitations because of cost and complexity.

The mill as a gage

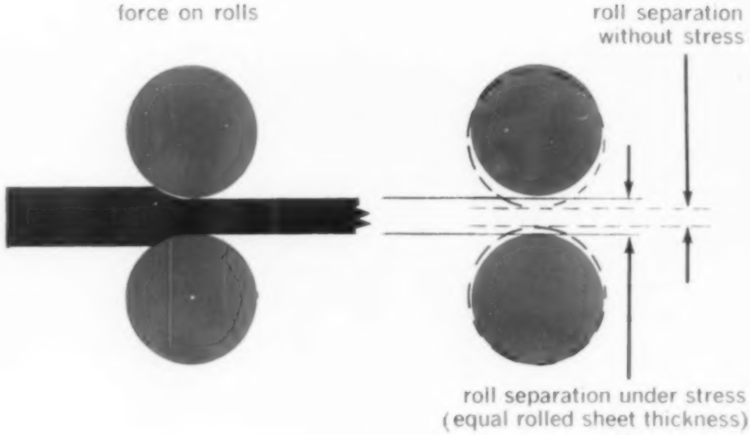
R. B. Sims *(see British patent No. 713,105)* and the British Iron and Steel Research Assn. have proposed a new approach to the problems of rolling-mill control. Their method involves using the mill stand itself to measure thickness of the rolled product.

The instantaneous determination of thickness by this system eliminates one major time delay in the feedback-control system, and opens the way to further improvements in mill performance.

The Sims method of gaging is based on the application of Hooke's law (stress is proportional to strain) and a few practical principles of instrumentation. The diagram at top, right, shows strip passing through rolls. Force exerted by the strip on the rolls increases roll separation from what it would be without stress.

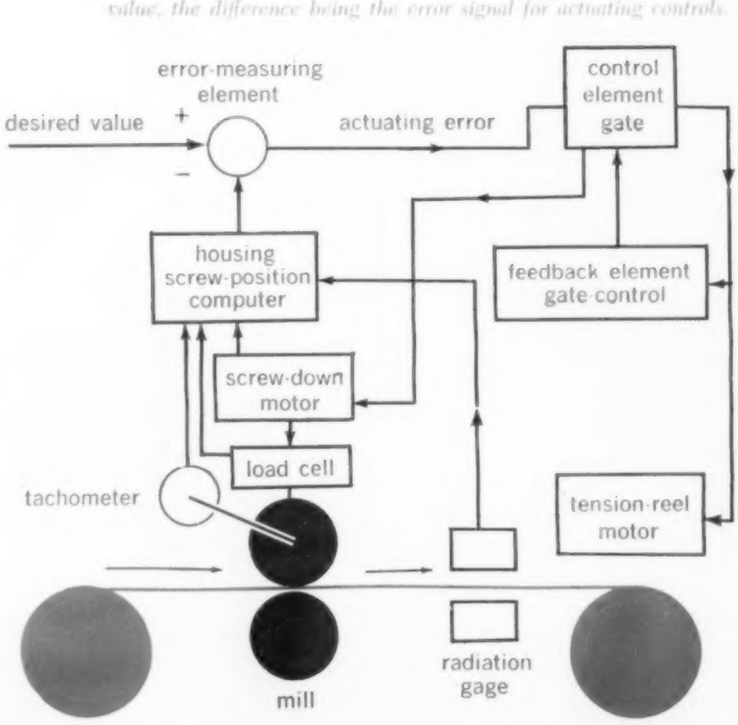
Individual deflections of mill housing, screws, and roll all contribute to the total roll deflection. This total deflection is a function of the force on the rolls and overall stiffness of the mill.

The thickness of rolled strip is equal to the unloaded roll separation (determined by mill setting) plus the total roll deflection (determined by force and mill stiffness). Transducers can be used to obtain voltages proportional to these quantities. The



STRIP STEEL THICKNESS *can be measured from initial roll separation, determined by mill setting, and roll deflection during operation, determined by force on the strip and stiffness of the mill (above).*

COMPLETE COLD-REDUCTION MILL *control system has controls for strip tension and mill screw position, in addition to radiation gage. Controlling strip thickness by adjusting tension helps reduce time delays in the overall system. The computer determines screw position principally from load-cell signal and from screw-position sensor. The tachometer is used to provide a correction during periods of acceleration, and the radiation gage compensates for average errors. The computer output is compared with desired value, the difference being the error signal for actuating controls.*



ystem at all.

sum is proportional to rolled-strip thickness.

To obtain a voltage proportional to mill setting, an electromechanical transducer is coupled to the mill screw. To obtain a voltage proportional to force, a load cell, or force-measuring transducer, is used.

Choice of load cells

The choice of load cells for a measuring system of this type in a steel rolling mill presents a problem. The cell must measure and transmit forces in the order of three- or four-million pounds, and must have a small height because of space limitations on many existing mills. An accuracy of about 0.5% is required in most gage-control systems.

Four commercial load cells considered included a five-million-pound hydraulic cell, a five-million-pound strain-gage load cell, a three-million-pound differential-transformer strain-sensitive load cell, and a new-type magnetic three and a half-million-pound stress-sensitive load cell. The fourth type, despite certain problems, has been selected for a control system now being installed.

There is justification for selecting a load cell for its repeatability rather than its absolute accuracy. This method of measuring—the use of housing strain and relative screw position—does not maintain high absolute accuracy.

An error may result from wear in the mill rolls, expansion of mill housing or rolls with temperature changes, or alterations in the mean vertical position of mill rolls with changes in bearing oil-film thickness. Any one of these can affect the product thickness.

Errors in absolute accuracy of the measuring system can be corrected by a contacting or radiation-thickness gage located on the output side of the mill stand. It must correct average errors and have a long response time.

Complete system for a reversing cold mill

The diagram at left shows a complete control system for a single-stand, reversing, cold-reduction mill. It incorporates both tension control and gated screw control. Since tension control of reduction is much faster than mechanical motions of the screws, this system has the advantage of eliminating one other time delay in the control system.

The range of compensation through tension control is limited to about ± 10% for cold rolling, so that it is necessary to have a gate-control element working from the level of tension in the tension reel. When the pre-set tension level is reached, the screws are brought into operation by the gate to relieve or increase the tension.

The control system described is used in Europe and Canada, and good results are being realized. The Canadian installation controls 0.0088-inch-thick cold-rolled strip over the major portion of the coils to within ±0.0002 inch on a reversing cold mill.

It is subject to errors due to effects of roll and bearing eccentricity, and changes in bearing oil-film thickness. In addition, if heavy reductions are taken on a narrow strip, deformation of the rolls may alter effective spring rate of the mill and create a measurement error.

While changes in average vertical position of mill rolls can be compensated for with a monitor gage, any changes that occur during start-up and slow-down and any variation in gage due to roll eccentricity may be too fast for monitor gage compensation. Errors introduced during acceleration periods may be compensated for using tachometer feedback from the mill rolls to the gage computer as shown in the system diagram.

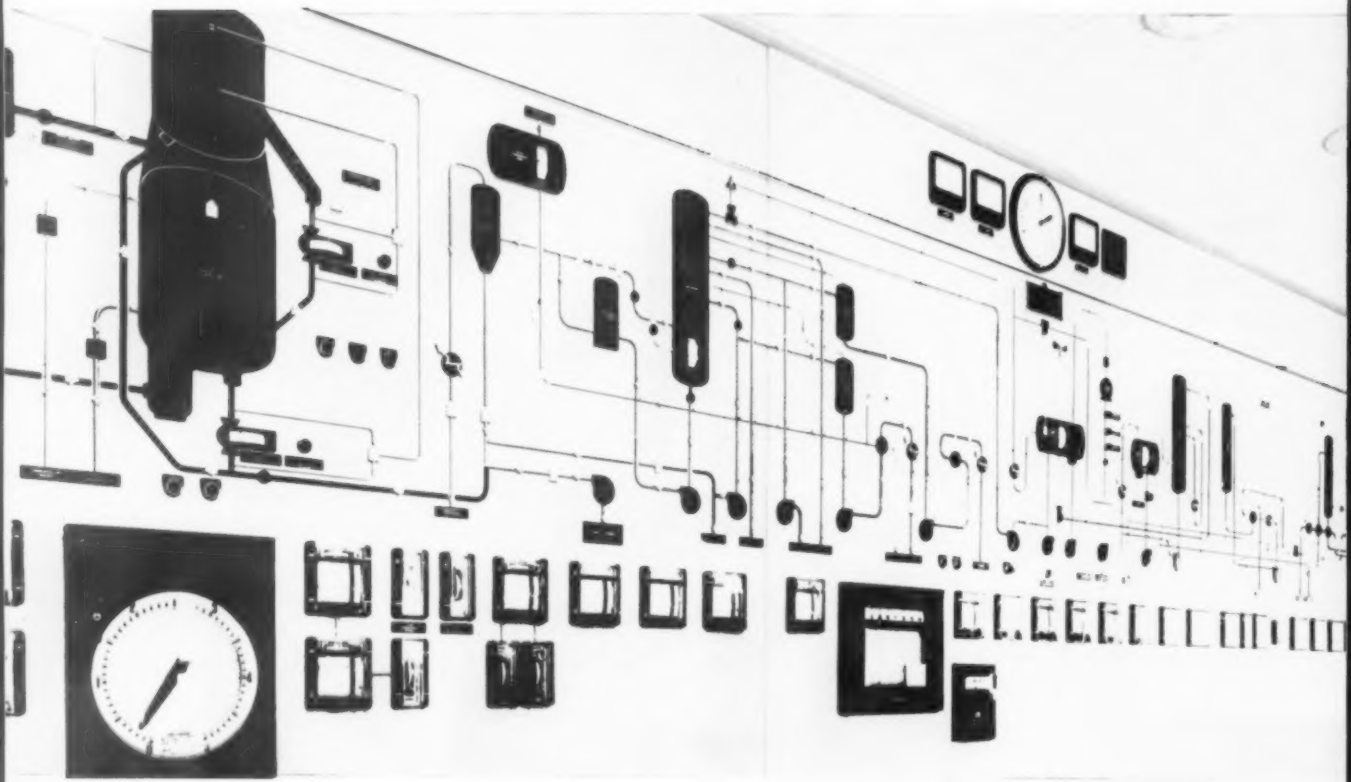
Force-screw-position gaging

Considering results already being obtained on *cold* rolling mills controlled by the "force-screw-position" method of gaging, there is no doubt of its value. A major problem in the rolling industry is automatic control for the tandem *hot-strip* mills. Evidence shows that gage variations in hot-rolled coils are responsible for gage variations in cold-rolled coils. A large portion of gage-control problems at the cold mill would disappear if the hot mills produced uniform gages.

Since the Sims method of gaging would not require equipment to be placed between the several stands of the tandem hot mill, the method appears ideal for hot-mill control. A monitor gage at the delivery end of the mill could serve several stands if need be, each stand having its own feedback control system.

Such a system currently is being investigated for wide hot-strip mills. Although conclusive results are not yet available, this type of installation eventually may be a part of the ideal automatic gage control system for hot-rolled strip. ■

(SEE TOP PAGE 93)



FIRST GRAPHIC-CONTROL PANEL, *developed in 1949, was made possible by miniature instruments. With this simplified flow diagram of the refining process, operators easily could see the relation between the process and individual instruments, reducing the possibility of their making a mistake.*

INSTRUMENTATION IS CHANGIN

by **David M. Boyd Jr.,** *head, instruments group, Universal Oil Products Co.*

PETROLEUM REFINING has been a continuous story of process improvement and a search for new control instrumentation techniques to make the best commercial use of these processes. Refining control and instrumentation techniques have passed through four stages: batch operation, hand control of continuous units, semi-automatic operation, and fully automatic operation with human direction.

Now the industry has approached the threshold of what may be its most dramatic phase—computer control of a complete refinery.

Oil in batches

The earliest refining units were batch stills. Crude oil was placed in a vessel and heated to a temperature sufficient to boil out desired gasoline and kerosene fractions. These products were sold at prices determined by product specific gravity, as measured by a hydrometer.

The second stage of development came shortly after World War I, when both knowledge and competition increased. Batch stills were replaced by more efficient, continuous columns. Furnaces at this stage of development had only a few burners, and control was manual.

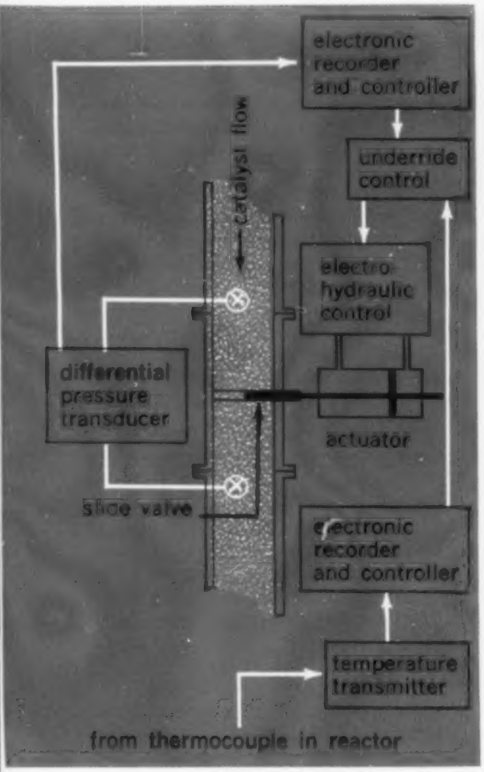
The hand-control method was used for many years. Other process variables were controlled similarly, with the operator taking readings and walking to the proper valve and adjusting it. Old-time operators knew the peculiarities of each unit in their charge. They had to have an intuitive feel of the time lag in the system.

Transition to the third stage of refinery control—use of semi-automatic devices—came with development of recording instruments. The true significance of these instruments is not that they simplified the operator's logging of instrument readings. Rather they provided a means of rapidly determining the *rate of change* of a given variable. The operator had a better chance to outwit lag by anticipation.

As instrumentation progressed, so did control. Fuel valves were furnished with feedback elements so the operator could control furnace temperature with a setting. Three essential ingredients of an automatic-control system were now present:

There was a way to anticipate heat demands; a way to hold heat input to desired levels; and a way to change heat input as the need for change grew.

As refineries continued to grow in



CATALYST FLOW *control system is the critical part of catalytic-cracking process.*

THE OIL INDUSTRY

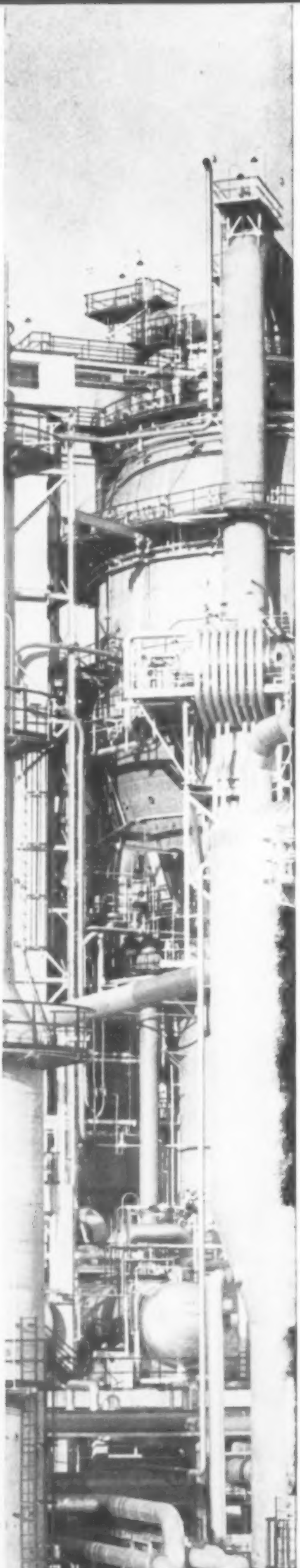
size and complexity, recording instruments and controllers were grouped in a central area. Originally the control panel was in a corner of the pump room, but rapidly outgrew this space until it was housed in a separate building. By the time World War II began, control panels of interrelated process units became 100 to 150 feet long.

The graphic panel

A radical development occurred in 1949, when Universal Oil Products Co. designed the first graphic-control panel. (See drawing above, left.)

Rock Island Refining Corp., of Indianapolis, was adding new processing equipment and decided to use newly developed miniaturized instruments. Because the new instruments required so little room, it was

At Universal Oil Products David Boyd's responsibility is the development and application of instrumentation to refinery and petrochemical processes. Previously, he was with Barrett Chemical Co., Blaw-Knox Co., and Oak Ridge National Laboratories. He received a BS in chemical engineering from the University of Colorado, and subsequently, the honorary degree, chemical engineer, for developing the graphic control panel. Boyd is a member of: the American Society of Mechanical Engineers, Instrument Society of America, American Institute of Chemical Engineers, American Chemical Society, and the Institute of Radio Engineers.



possible to lay out the control panel in the form of a simplified flow sheet picturing the process.

Advantages of the graphic panel were obvious. Operators easily could see the relationship between the process and individual instruments, with less possibility of reading the wrong recorder or operating the wrong valve.

Refinery engineers quickly adapted the new panel package, but with mixed success. Some, confusing the merits of the packaging with those of the new instruments, designed extremely complex graphic panels using older-style instruments and controllers with which they were familiar. Control precision suffered.

Electronic control techniques made tremendous strides after WW II. Reliability of electron tubes, relays, and other components increased sufficiently to warrant their consideration for critical process control. During the same period, process designers came to regard instrumentation as an integral part of the design—not merely an accessory to be fitted to a preconceived pattern.

The immediate benefit of electronic controls was greatly increased precision and speed of response. Elimination of mechanical linkages reduced the temperature differential required to trigger a change in the position of a valve. Similarly, electronic connections between pick-up and actuator points reduced time lags materially.

Catalyst control

In 1958 the first electro-hydraulic control system went into operation at the Port Credit, Ont. refinery of Regent Refining Ltd. (Canada). This system is an example of an electro-hydraulic control. The problem in fluid catalytic cracking is to transform heavy oil into gasoline and light fuel oil by applying heat and pressure.

In "fluid" catalytic cracking, a catalyst (such as alumina), in the form of finely divided solid particles, flows through the reactor or cracking unit, mingling with the oil. Control of catalyst flow is the most critical part of the process. As catalyst flow is increased, temperature in the reactor is increased.

Precise catalyst flow effects the desired reaction and prevents the possibility of explosion in the reactor. Temperatures must be maintained at about 900 F. This is done by varying the flow of catalyst to the reactor with a slide valve. With up to 15 tons of catalyst circulating per minute, small changes in the position of the slide valve affect reactor temperature considerably.

With the electronic control system shown in the diagram on p. 93, any change in reactor temperature is sensed by a thermocouple, and its signal is used to correct the slide-valve position. If the differential pressure across the slide valve drops below a set level, the differential pressure controller takes over control and opens the slide valve enough to maintain proper catalyst flow.

This action is accomplished by an underride unit, which receives a signal from the differential pressure controller. The underride unit causes the temperature controller to be ignored, and the pressure difference across the slide valve then determines valve position.

Direct control via computer

The refining industry now is showing signs of moving into the fifth stage—direct process control by means of electronic computer. The groundwork has been prepared by electronic instrumentation, which provides signals easily connected to a computer.

But at the current state of the art, computers have to be evaluated for each application. The economics of refining favors more precise control even at higher cost. A refinery processing 30,000 barrels of crude daily (a medium-sized plant) handles $90,000-worth of raw materials each day. A small increase in efficiency could save a large sum of money.

The trend in refinery operation has been toward increased flexibility to accommodate changes in demand, such as from aviation gasoline to jet fuel. There also is a trend toward increasing facilities without increasing personnel. Better control and instrumentation systems have relieved operators of much routine work, freeing them for jobs requiring higher skill.

Computers have been tried out on refining and chemical process units with some success. But computer control is roughly where electronic controls were about 10 years ago. Progress probably will be made at an accelerated rate, with emphasis on simplified circuits for lower cost and solid-state components for longer life and greater reliability.

If further studies bear out expectations of computer enthusiasts, the refining industry should be well into its fifth stage of development by 1965.

Meanwhile, refiners will improve their operating efficiency and lay the foundation for possible computer applications by upgrading their instrumentation and control systems —and the men who will operate them. ■

What Motivates the Technical Man? —I·R survey results

THE HEADLINE might be phrased more properly as "What motivates the technical man who reads *Industrial Research*?" While I·R readers include engineers, research scientists, and technical management men at all levels of responsibility in their organizations, the survey (see Apr-May 1960 issue, pp. 19, 20) proved of greatest interest for finding what men in middle management think about research needs, their company, their associates, and themselves.

Forms were still coming in, but at the deadline, 332 completed questionnaires were received, representing slightly more than 1% of circulation for that issue. Almost all questionnaires indicated that the individual had read the article, "The Technical Entrepreneur," (Apr-May issue, p. 10), which posed some questions and suggested some solutions on the role of research in the next decade.

Most are technical management

What kind of men sent in replies?

Almost all characterize their work as research or engineering, or both. The great majority have attained the level of senior or chief engineer, or research or engineering department head or assistant head.

About three-fifths of the total have patents granted, pending, or being filed. Of these, the median has four granted, two pending, and one being filed. Almost 80% have published at least one technical paper; of these, the median is three papers.

More than 95% of those replying have received at least one college degree; 20% have a master's; and 20% have a doctorate. Ninety-five per cent are married (Do single men fill out questionnaires?), and 85% of these have children.

If you are an average I·R reader, you are working at your third job and have been there eight years. You have about 15 years professional experience. Chances are that approximately half of you are republican, one-third are independent, and one-sixth are democratic.

Some 60% of you work for a large company (over 1,000 employes) and 30% work for a medium-sized company (100-1,000 employes).

The morale of most of the technical men surveyed is pretty good: replies indicated that you usually respect your superior and think you are performing your own responsibilities with respect to your subordinates. Opinions regarding communication within an organization are interesting. Most of you believe communication within your company *is not* adequate, but that within your department or section, communication *is* adequate.

I·R readers' median salary is $14,200

Next consider the average man's salary, not always the prime professional motivation, but always the most interesting part of questionnaire returns. Salaries ranged from $6,000 to $44,000, the median being $14,200 a year. Within the same company, the average man has been promoted between one and two times.

How does salary depend on years of professional experience, academic training, and title within an organization? As could be expected, salary increases with experience, but there is a leveling off after 15 years. However, this may be a bias in the returns.

Salaries of those with bachelor's and master's

A note on circulation to I·R advertisers

Industrial Research has been working hard to define its audience, in quantity[1] and quality.[2]

1. Total circulation (print run) of this issue is 51,000—an increase over base circulation of 31,000—at no increase in advertising rates.

Now, *Industrial Research* proudly announces it will maintain an increased, audited, circulation for the balance of the year. A minimum total circulation of 41,000—an increase of 32%—will be guaranteed at no increase in rates for the balance of this year.

2. After a year and a half of publishing, I•R has defined its quality of circulation to a fine point. The magazine is read by these three overlapping groups:

- Industrial research and development men in the laboratory.
- Creative engineers (creative because it is their job to apply the results of industrial research).
- Technical directors and other executives concerned with the ideas and applications of research from the management viewpoint.

These are the men who decide on your products and services.

The *average* I•R reader earns $14,200 a year, holds "two" patents, has 15 years experience, spends one-and-a-half hours with this magazine each issue, reads employment ads in I•R, and is charged in his company with specifying industrial products or services. *(For a comprehensive survey of these readers, turn to the article on page 95.)*

degrees was nearly the same, about $14,000. Those with no degree averaged under $11,000, and those with doctorates averaged about $16,500.

Comparing salaries versus titles gave results that might be expected, except that the median vice-president earned a lot more than the median president. This may be due partly to the small number of returns from vice-presidents (22) and presidents (12). Also the vice-presidents may have been mostly from large companies and the presidents from smaller companies.

About half of those replying think they are a technical entrepreneur (defined in the article as a Thomas Edison-type—one who combines innovating and risk-taking abilities). But almost all think we need more of these people.

Engineering versus management

What about opportunities to advance, comparing engineering and management positions? Eighty-seven per cent think management offers more opportunity in this respect. Almost two-thirds are in management; but more than half would prefer engineering work if salary and opportunity were equal.

Other factors pertinent to attitude and morale were covered by the questionnaire. All but 20% read employment ads in I·R at least sporadically, and 30% read them regularly.

Of those replying, more than 96% specify industrial products or services, and the average time spent reading I·R is one and a half hours.

Following are the results in detail:

1. How would you characterize your work?
289 replies: *research—201, engineering—233*

2. Do you consider yourself a technical entrepreneur (or the kind of person who will become one)?
yes—186 no—133 possibly—116

3. Have you read the article about the technical entrepreneur preceding this questionnaire?
yes—323 no—9

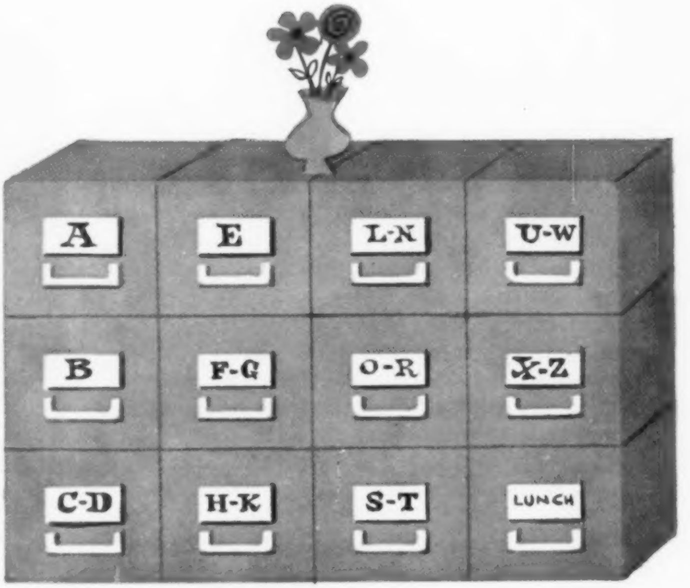
4. Do you agree with the point made in the article that this nation needs more technical entrepreneurs to effect a high rate of national economic growth?
yes—287 no—2 undecided—27

5. How many patents do you have?

PATENTS	GRANTED	PENDING	BEING FILED
1 or 2	*70*	*80*	*56*
3 to 6	*48*	*49*	*29*
7 or up	*47*	*7*	*5*

6. How many technical papers have you published?

NUMBER PAPERS:	0	1	2	3	4	5	6-10	11 OR MORE
Replies:	*27*	*44*	*37*	*29*	*19*	*15*	*37*	*51*



Four Filing Cabinets of Vital Information in

COMPONENTS DIGEST HANDBOOK 1

18 months ago the magazine – ELECTROMECHANICAL DESIGN – initiated a series of studies of important electromechanical components in use today. The series, titled "Components Digest," has been a widely acclaimed feature of the magazine ever since.

Now, nine of these exhaustively researched studies have been collected and published as COMPONENTS DIGEST HANDBOOK No. 1.

The handbook is designed specifically to give the busy design engineer a complete survey of each subject. To enable him to select and specify the proper components.

Each category is thoroughly examined, documented and extensively illustrated with photos, charts, tables, diagrams and exploded views of components and their performances. You will find complete

Descriptions of types, sizes and measurements
Construction Information • Design Applications
Selection Factors • Performance Characteristics
Military Specifications
Reliability Assessments
Nomenclature and Definition Tables.

If you were to assemble all of the data from all of the sources involved it would easily fill four filing cabinets.

The handbook makes a rich sourcebook of design information. One that neither you nor your company can afford to be without. THE PRICE – $7.00.

CONTENTS OF HANDBOOK NO. 1

1. Instrument Servo Motors
2. Precision Potentiometers
3. Electromagnetic and Potentiometer Transducers
4. Environmental Testing
5. Sensitive Relays
6. Connectors and Fasteners
7. Analog-Digital Converters
8. Electromechanical Switches
9. Fractional Horsepower Motors

Clip and Mail Today to
ELECTROMECHANICAL DESIGN
1357 WASHINGTON STREET, WEST NEWTON 65, MASS.

Please send me _____ copies of Components Digest Handbook No. 1.
I enclose _____ payment at $7.00 per copy.

NAME (please print) _____

COMPANY _____

STREET ADDRESS _____

CITY _____ ZONE _____ STATE _____

7. What per cent of gross sales is spent for all R&D in your company?

PER CENT:	LESS THAN 1%	1%	2%	3%	4%	5%	6-10%	11-15 %	16%-UP
Replies:	*22*	*24*	*37*	*26*	*10*	*27*	*17*	*3*	*30*

8. What is the highest degree you hold?

	NO DEGREE	B.S.	M.S.	Ph.D.
Replies:	*14*	*191*	*63*	*60*

(Also see "salary and training" table.)

9. What is your employment level?
assistant engineer—21, associate—25, senior or chief—109, department head or assistant head—136, vice-president—22, president—12
(Also see "salary and title" table.)

10. What is your annual base salary?
(Annual figures, bonus included)

SALARY:	\$6,000*	\$7,000	\$8,000	\$9,000	\$10,000	\$11,000
Replies:	*3*	*8*	*17*	*26*	*34*	*25*
SALARY:	\$12,000	\$13,000	\$14,000	\$15,000	\$16,000	\$17-19,000
Replies:	*22*	*29*	*23*	*31*	*19*	*38*
SALARY:	\$20-24,000	\$25-29,000	\$30-39,000	\$40,000-UP		
Replies:	*29*	*5*	*14*	*6*		

* (\$6,000 to \$6,999, etc.)

11. Do you feel your formal education has prepared you adequately for your *engineering—216, research—151, or administrative—112* function?

12. Are you listed in *American Men of Science, Who's Who in Engineering*, or in a similar directory?
yes—121 no—190

13. Is your present place of employment your 1st, 2nd, 3rd, 4th, 5th, 6th, or more since graduation? How long have you worked at your present company?

PLACE:	1ST	2ND	3RD	4TH	5TH	6TH OR MORE
Replies:	*59*	*85*	*65*	*51*	*31*	*37*
YEARS:	1	2 OR 3	4 TO 6	7 TO 10	11 to 20	21-UP
Replies:	*29*	*44*	*73*	*66*	*88*	*30*

14. About how much *more* money did you get on the average per year when changing jobs?

DOLLARS:	NONE	0-\$300	\$301-\$600	\$601-\$1,000	\$1,001-UP
Replies:	*54*	*33*	*43*	*39*	*82*

15. How many times have you been promoted in your present company?

TIMES:	0	1	2	3	4	5 OR MORE
Replies:	*51*	*63*	*68*	*50*	*22*	*32*

16. Do you believe engineering, or management, offers the greatest opportunity to an engineer to advance?
engineering—39 management—289
Which of these directions have you chosen for your own career?
engineering—112 management—206
If all other considerations were equal (salary, opportunity, etc.) which type of work would you choose?
engineering—180 management—138

17. What is your total professional experience (excluding college)?

YEARS:	TO 1	TO 2	TO 4	TO 6	TO 10	TO 15	TO 20
Replies:	*2*	*5*	*13*	*10*	*75*	*61*	*72*
YEARS:	TO 30	OVER 30					
Replies:	*65*	*27*					

(Also see "salary and experience" table.)

SALARY AND EXPERIENCE
(correlation of questions 10 and 17)

YEARS EXPERIENCE	NUMBER OF REPLIES	MEDIAN SALARY	RANGE
to 1	2	\$ 7,500	\$6- 8,000
to 2	5	8,300	7- 9,000
to 4	13	9,000	7-13,000
to 6	10	11,200	8-18,000
to 10	75	11,000	8-23,000
to 15	61	15,800	8-44,000
to 20	72	15,300	6-40,000
to 30	65	18,400	9-40,000
over 30	27	16,300	8-40,000

SALARY AND TRAINING
(correlation of questions 8 and 10)

DEGREE	NUMBER OF REPLIES	MEDIAN SALARY	RANGE
None	14	\$10,800	\$6-40,000
Bachelor's	191	14,000	6-40,000
Master's	63	14,000	7-44,000
Doctorate	60	16,500	8-40,000

SALARY AND TITLE
(correlation of questions 9 and 10)

TITLE	NUMBER OF REPLIES	MEDIAN SALARY	RANGE
Assistant	21	\$10,000	\$ 6-16,000
Associate	25	10,800	7-32,000
Senior or chief	109	12,500	8-40,000
Dept. head or ass't.	136	15,700	6-39,000
Vice-president	22	26,000	18-44,000
President	12	18,000	15-40,000

An I•R survey reveals technical salaries and tells what engineers, scientists, and technical executives think about research needs, their companies, their associates, and themselves.

18. Do you now work: *for a large company (1,000 or more employes)—202; medium-sized company (between 1,000 and 100)—97; for a small company (under 100)—25.*

19. What is your political affiliation: *republican—151, democrat—58, independent—109, other—7.*

20. Do you feel communication is adequate throughout your company?
yes—82 no—250

21. Do you think the missile race with the Soviet Union could be improved in favor of the U.S. by spending *more for research—(110); more for education—(104); other—(133).*
Typical "other" comments, in their order of frequency, were:

- *Improving technical competence.*
- *Change in philosophy of education.*
- *Training technical entrepreneurs.*
- *Better utilization of research.*
- *Get more thinking people on the job.*
- *Better funding arrangements.*
- *Remove political inefficiency.*
- *Technical communications.*
- *Demand quality and results.*
- *Better integration.*
- *Recognition of professional effort.*
- *Less on prosaic defense.*
- *More efficient utilization of funds spent.*
- *More toward establishing a world government.*
- *Less public hysteria.*

22. Do you exert an influence in specifying industrial products or services?
yes—284 no—38

23. If your immediate superior is a technical supervisor, research director, vice-president of engineering or research, please answer the following:

a. Do you feel your boss is technically (scientifically) qualified for his job?
highly so—117 average—110 poorly—36

b. Is he sufficiently sensitive to your technical or professional problems?
yes—168 no—90

c. Is he sufficiently sensitive to your personal problems including salary requests?
yes—177 no—76

d. Do you think he is effective in getting an equal share of appropriations, salary raises, equipment, etc. for his department or section?
yes—158 no—92

e. Do you feel your boss takes an important and as active a part in management decisions as he should?
yes—128 no—124

24. If you are a project leader, technical supervisor, chief or senior engineer or scientist, or vice-president of research or engineering, please answer the following:

a. Do you feel the men in your research laboratory are unduly sensitive?
yes—63 no—214

b. Do you consider morale a key factor in research creativity?
yes—272 no—10

c. Do you take as active a part in the overall management of your company as does the nontechnical executive?
yes—133 no—151

d. Are you as effective in getting equipment, appropriations, and salary raises for your department or section as are the nontechnical department heads in your company?
yes—201 no—168

25. Are you married—*314;* single—*16;* have children?

NUMBER OF CHILDREN:	1	2	3	4-UP
Replies:	*44*	*100*	*77*	*53*

Do you have boys between the ages of 8 and 18?

NUMBER OF BOYS:	1	2	3-UP
Replies:	*76*	*42*	*14*

Do you have girls between the ages of 8 and 18?

NUMBER OF GIRLS:	1	2	3-UP
Replies:	*73*	*34*	*13*

If so, are you trying to interest them in science?
yes—148 no—37

26. Was your father, brother, uncle, or someone else in your family a scientist, engineer, or technical executive?
yes—99 no—223

27. Do you read employment ads in this magazine?
regularly—92 sporadically—170 never—68

28. About how much time did you or will you spend reading this issue (Apr-May) of *Industrial Research*?

TIME (hours):	TO ½	TO 1	TO 2	TO 3	TO 4	OVER 4
Replies:	*37*	*102*	*129*	*27*	*12*	*17*

ADVERTISERS' INDEX

(continued from page 9)

FEEDBACK *from readers*

Nuclear radiation energy

Sir:

This article is a good evaluation of a complex subject. It should be valuable to those who might be considering investing in attempts to use radiation for power or for other uses.

I hope that in future issues you will emphasize more and more the problems of research. There is too little information available about techniques for planning, carrying out, evaluating, and reporting research.

Lewis E. Walkup
Columbus, Ohio

Ultrasonics

Sir:

I have read the article, "Ultra- and Hyper-sonics," with great interest and am sending it around to my staff for reading.

Leo L. Beranek
President
Bolt, Beranek & Newman Inc.

Sir:

I am very interested in the article in the April-May issue on Ultra- and Hyper-sonics as related to the sterilization of milk. Could you tell me where to write for information?

Forest Tilton
Work Simplification Dept.
H. P. Hood & Sons

(Mr. Tilton was referred to several manufacturers of ultrasonic equipment.)

Oceans of business opportunities

Sir:

I found Adm. Momsen's article stimulating. But I noticed the article states incorrectly that the French are considering a sea thermal energy installation at Adibjan. Actually, the French have abandoned their plans to complete this installation due to poor planning and conflicting interests.

During the past year the R&D department of my company has been conducting design studies and building devices for exploring this one remaining frontier on our planet. We have completed a design study of a power plant, utilizing this principle, for erection in underdeveloped countries.

These studies show that almost 40% of the gross output of the plant is required to operate the plant and some 60% of the gross output is left for external consumption. My paper on this will appear in the Winter Journal of the Assn. for Applied Solar Energy.

Asa E. Snyder
Director, Research & Development
USI Clearing Div.
U. S. Industries Inc.

Corrosion, an enigma

Sir:

The article "Corrosion, an Enigma" is of some interest as a thought-provoking item. It does not contribute anything new on the topic, possibly because there is nothing really new that has occurred.

From a practical point of view, we are still working with antiquated test methods that are of questionable value and that are misapplied more often than not.

W. F. Bonwitt
Chief Engineer,
Omaton Div.
Burndy Corp.

De-salting saltwater

Sir:

I am writing to tell you how much I enjoyed the article on salt water in the Feb-March issue. I can appreciate the amount of research required to cover the subject as thoroughly as you did.

D. E. O'Connor
Chief Engineer,
Houston Div.
Commonwealth Services Inc.

Sunpower

Sir:

I have read the article "Sunpower" in your Apr.-May issue with great interest. It is gratifying to see for once that many of the organizations working in this field appear to be doing so without government support.

So much basic research work going on would not be done at all, if it were not for international competition and resulting government spending. It is regretable that research and development in many companies means merely coming out with a modified line of products next year, or testing the ones now being made.

Arnold G. Johnston
Denver, Colo.

General feedback

Sir:

I appreciated reading your excellent publication. I leave no stone unturned to do so. But I wish you would provide the reader-inquiry cards you used to have.

As a qualified photographer and appreciator of the arts, I find that your photography, art placement, and use of toning enthralls me.

M. M. Brauer
Engineer
Nortronics Div.,
Northrop Corp.

(We have found that I•R readers are more likely to write a letter than to fill out a reader-inquiry card, so we discontinued the cards.)

Sir:

We very much appreciate your excellent magazine.

Paul F. Maginnis
Professional Placement Associates

Sir:

Industrial Research is held in high regard by Corning personnel.

Archer N. Martin
Corning Glass Works

Sir:

I recently picked up a copy of *Industrial Research* and find it most interesting and directly applicable to a great deal of my work. Keep it up.

Jack D. Selkin
Chief, Weapons & Fire-Control Branch
Boston Ordnance District

Sir:

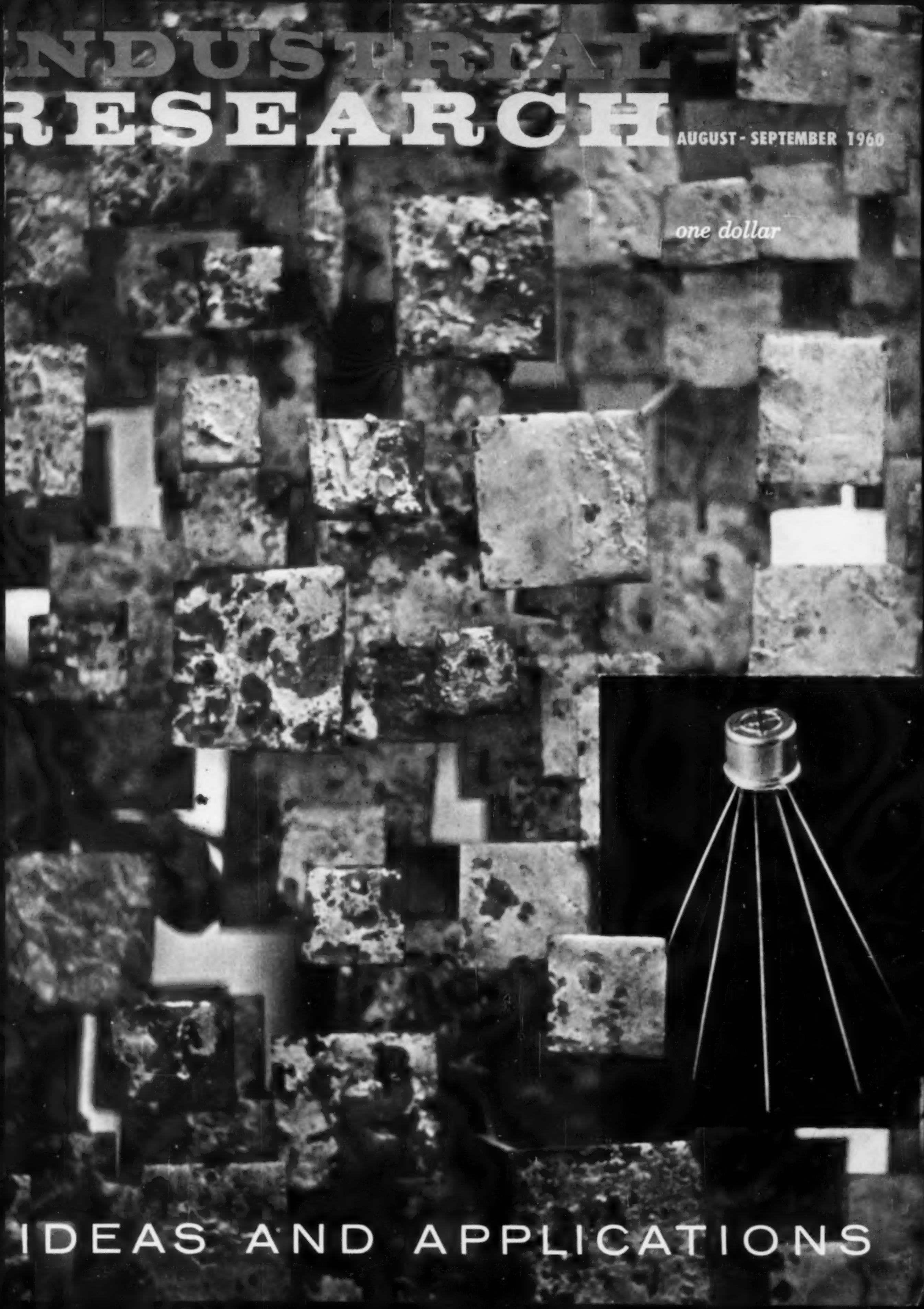
We have recently subscribed to your magazine. It is one of the better types for our business. It contains a world of information on the various types of research and research problems. I think it should be valuable to everyone in the research field.

Jack M. Lepp
Asst. General Supt.
The Carlyle Tile Co.

Sir:

The Apr-May issue is a beautiful piece of work, inside and out. Congratulations and best wishes for continued success.

John J. Raffone
Bell Telephone Labs.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